MEMORANDUM

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To: Mike Rowe, IDEQ

Date: June 18, 2008

From: Roger Wilson, MWH

Reference: P4 Production

Subject: Submittal of *Final - 2008 Phase IIb Monitoring Well Installation Technical Memorandum – Revision 2*

Dear Mr. Rowe-

Please find enclosed the *Final 2008 Phase IIb Monitoring Well Installation Technical Memorandum Revision 2*. With incorporation of revisions and submittal of this document, P4 Production considers the document approved by the Agencies and Tribes as stipulated in your May 22, 2008 letter.

This document will be transmitted electronically and in hard copy as indicated below. The whole document will be uploaded to the ftp site and the CD but only *modified sections will be sent as hard copy*. The modified sections include the: Response to Agencies and Tribal Comments on the *2008 Phase IIb Monitoring Well Installation Technical Memorandum - Revision 1*, main document, Section 4 of Appendix A and all of Appendix B. Please retain the drawings and Appendix A (with the exception of Section 4) to incorporate in the final copy of the document.

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Agencies and Tribes Comments on *2008 Phase IIb Monitoring Well Installation Technical Memorandum, Revision 1*, April 2008

Previous Comments

Comment G. Neither geologic reconnaissance of the basalt area near Little Blackfoot River nor water balance for waste dumps and Wells Formation at Henry Mine seemed to be included in Appendix B as indicated by the response. Either identify where these tasks are mentioned or add them as work to be done in 2008.

<u>Response:</u> *The following text has been added to the description for Activity 3c-1 – Complete Direct-Push Groundwater Sampling Program*

"During the direct-push program, a reconnaissance of the Little Blackfoot River, north of MMP043, will be conducted to learn if there is a shallow alluvial groundwater system overlying the Quaternary Basalt. If a shallow alluvial groundwater system is observed, additional direct-push locations will be advanced to characterize potential selenium contamination within the shallow alluvial groundwater system."

Regarding the water balance modeling, an additional activity (Activity 3c-10-- Water Balance Modeling at Waste Dumps and Wells Formation at Henry Mine), and a description of the task was added to the program work breakdown structure contained in Appendix B.

Comment I. P4/Monsanto's response is insufficient. Please provide the Stiff and Piper diagrams/plots as required. P4/Monsanto may provide additional forms of data presentation should they so desire.

<u>Response:</u> *The data will be provided in the Draft Interim Report for Hydrogeologic Investigation - 2007 Hydrogeologic Data Collection Activities and Updated Conceptual Models - Revision 2.*

Comment 20. The response indicates that the text was revised although it does not appear that it was. Please revise.

<u>Response:</u> *Comment noted. The following text has been added: "(If excessive fines are encountered in formational material, the field geologist may choose to install 0.010-inch slotted screen)"*

New Comments

1. Page 9, Section 3.3 – It should be Table 5.1 (Section 5.0). Please revise.

<u>Response:</u> *The text has been revised.*

Appendix B-2

2. Page 5, Groundwater Analyses—In addition to the 6 COPCs, which are being analyzed for both total and dissolved concentrations, analytes for which there are primary constituent standards in the Ground Water Quality Rule should be analyzed on a total basis. Please revise accordingly.

Response: *The text has been revised as follows:* "All analyses will be on a total basis, in addition, the COPC metals identified in the AOC will be analyzed for dissolved concentrations.

3. Page 6, Table B-3 – The EDL for lead is 0.04mg/L, which is too high when the groundwater standard for lead is 0.015 mg/L. The EDL for lead in the *Monitoring Well Installation Technical Memorandum for Final 2005 Phase II Supplemental SI Groundwater Work Plan, Version 5* was 0.0001mg/L. Please modify as necessary.

Response: *Table B-3 has been modified.*

4. Page 6, Table B-3 – Eliminate the asterisk (*) and plus (+) flags from magnesium as Mg will need to be analyzed at all sties for which geochemical typing is to be done.

Response: *Table B-3 has been modified.*

5. Page 6, Table B-3 -- The footnote identified by an asterisk (*) should read "Analytes to be analyzed in groundwater collected from monitoring wells MMW007, MMW009, MMW010, MMW012, MMW014, MMW017, and MMW018, and surface water at sites not previously sampled for the expanded list of analytes".

Response: *Table B-3 has been modified.*

Prepared for:

P4 PRODUCTION

Final
2008 Phase IIb Monitoring Well Installation Technical Memorandum

Revision 2

Enoch Valley, Henry, and Ballard Mines

June, 2008

Prepared by:

MWH

Bellevue, Washington

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1.0 INTRODUCTION

The purpose of this memorandum is to provide information regarding the monitoring well installations and groundwater sampling to be completed in the field season of 2008 at P4 Production's (P4) Enoch Valley, Henry, and Ballard mines as shown on Drawing 1.

This technical memorandum is being submitted as a deliverable under the Consent Order/Administrative Order on Consent for the Performance of Site Investigations and Engineering Evaluations/Cost Analysis (EE/CAs) at P4 Production, L.L.C Phosphate Mine Sites in Southeastern Idaho (08/20/03), EPA Docket No. CERCLA-10-2003-0117.

The approximate locations of the proposed monitoring wells are shown on Drawings 2 and 3. The subsurface conditions in the vicinity of the proposed monitoring well locations are shown on the Geologic Sections presented on Drawings 4 through 8. A description of the well locations, estimated total depths, targeted geology, and primary purpose of each well is summarized in Table 3.1. Proposed well construction details are provided in Table 3.2.

The rationale for selecting proposed monitoring locations is based primarily on the results of the 2007 hydrogeologic data collection activities summarized in MWH (2008a). Some of the proposed monitoring well locations may be adjusted pending the results of the 2008 direct-push groundwater sampling investigation (MWH 2008b).

This document does not present the comprehensive data and background information for the overall project. This information is contained in the 2007 Monitoring Well Installation Technical Memorandum (MWITM) (MWH, 2007). For information regarding Program Area and Physical Description, refer to Section 2.0 in the MWITM. Health and safety procedures are found in the Health and Safety Plan in Appendix I of the MWITM.

In general, standard operating procedures for field work activities to be completed in 2008 will follow those outlined in MWH (2007) with the following exceptions. Boreholes completed in the 2007 study were advanced using an Atlas Copco TH-60 air-rotary drill rig. For the 2008 boreholes, either a dual-wall reverse air-rotary drill rig or a rotary sonic drill rig will be used. These two methods of drilling will allow for better identification of first water, particularly when encountered in the shallow alluvial flow system. Standard operating procedures (SOPs) for each method are included in the Appendix.

Hydrogeologic testing of the aquifer materials will be completed in the 2008 field season. As indicated in the Draft Direct-Push Groundwater Sampling Work Plan, Ballard, Henry, and Enoch Valley Mines (DDPGS Work Plan) (MWH, 2008b), hydraulic conductivities will be assessed in the shallow alluvial flow system at select locations using a pneumatic slug test system. This pneumatic slug test procedure will also be used to assess the hydraulic conductivities of the deeper monitoring wells completed in the Wells Formation and deep sections of the Dinwoody Formation. Conventional slug testing will also be used to assess the hydraulic conductivities in the aquifer material in the shallow monitoring wells completed in the Dinwoody Formation. SOPs for both of these methods are provided in the Appendix.

In addition, Appendix B contains the program work breakdown structure for activities to be completed in 2008 in addition to activities outlined in the body of the report. These activities include:

- Completing the direct-push groundwater sampling investigation;
- Preparing the 2008 Monitoring Well Technical Memorandum and installing eight monitoring wells;
- Evaluating alluvial/colluvial and bedrock hydraulic conductivities;
- Sampling existing groundwater monitoring wells and groundwater level monitoring;

- Completing a seep/spring survey northeast of monitoring well MMW022;
- Confirming Wells Formation groundwater flow direction- Henry Mine;
- Evaluating flexure area in the northern portion of the Enoch Valley Mine;
- Completing the geochemical typing of wells, seeps, and springs;
- Evaluating mass wasting at waste dump sites; and
- Revising the conceptual hydrogeologic site model.

2.0 SUMMARY OF 2007 HYDROGELOGIC INVESTIGATION AND PROPOSED DIRECT-PUSH GROUNDWATER SAMPLING INVESTIGATION

The following summaries are based on information contained in MWH (2008a) and MWH (2008b).

2.1 2007 HYDROGEOLOGIC INVESTIGATION

The results of the 2007 hydrogeologic investigation were submitted to the Agencies for review on February 1 and April 16, 2008 (MWH, 2008a). The 2007 hydrogeologic investigation focused on characterizing the nature and extent of potential selenium contamination in the groundwater flow systems at the Enoch Valley, Henry, and Ballard mines. The investigation was conducted in a phased approach, such that initial phases of work focused on information gathering and development of site hydrogeologic conceptual models. Phase I work incorporated gathering easily accessible chemical data from the sampling of seeps, springs and existing groundwater wells to identify specific areas of interest and areas in need of further investigation. The Phase II program focused on collecting new data to specifically characterize groundwater flow and potential impacts associated with the mine areas.

Sixteen monitoring wells were installed to assess the shallow/alluvial, intermediate, and regional groundwater flow systems. The monitoring wells were installed at locations that represent the key, worst case, groundwater flow pathways. Groundwater samples were collected from each of the monitoring wells and analyzed for selenium.

Five of the sixteen monitoring wells were installed at the Ballard Mine area, and selenium was detected in groundwater samples collected from all five monitoring wells. Groundwater collected from two of the Ballard Mine monitoring wells had concentrations of selenium that exceeds the groundwater quality standard. Elevated selenium concentrations are found in the local alluvial and regional (Wells Formation) flow systems at the Ballard Mine. The Dinwoody Formation is present in the Ballard Mine area, but groundwater flow in the formation is best characterized as a local flow system. Groundwater data collected from the uppermost portion on the Dinwoody Formation in the vicinity of monitoring well MMW018 suggests a vertical concentration gradient in the alluvial system consistent with a surficial source of contamination – i.e., a waste rock dump. Groundwater flow in the Wells Formation is conceptualized to be to the northwest based on the structural grain of the geology in the Ballard Mine area. Faulting in the Ballard Mine area appears to have compartimentalized the groundwater system limiting flow.

Groundwater samples collected from the 11 monitoring wells installed in the Henry and Enoch Valley Mine areas did not have concentrations of total selenium that exceeded the groundwater quality standard of 0.05 mg/L, and groundwater samples collected from seven of the monitoring wells did not have detectible selenium.

Data provided no indication that there is a significant impact to the regional groundwater flow system in the Henry or Enoch Valley mine areas. At the Henry Mine, flow in the regional system is likely to the northwest. Monitoring wells MMW011 and MMW023 are well positioned for monitoring the regional system; however, well head elevations are needed for each of the monitoring wells to confirm the northwest trending flow direction. In 2008, a survey will be completed of the well and data will be used to confirm the regional groundwater flow direction. At the Enoch Valley Mine groundwater flow in the regional system is also likely to the northwest and monitoring wells installed in 2007 are well positioned to monitor this flow system. To assess the flow direction and gradient southeast of the mine, one monitoring well, MWW026 will be installed in 2008.

Where impacts have been observed there is a pattern of lower levels of contamination with increasing depth. Groundwater springs discharging from the shallowest portion of the alluvial system, when contaminated, display generally higher levels of selenium than do deeper contaminated portions of the alluvial system, which in turn is less impacted than the bedrock flow systems.

In general, the Enoch Valley and Henry mine areas were found to be less impacted than the Ballard Mine area. A significant reason for this is likely the higher level of reclamation completed at the two more modern mines. Age, as it relates to travel time and extent of weathering of the waste rock, may also be a factor, but in many cases at Henry and Enoch Valley the groundwater has been evaluated very close to potential sources without observed impacts to the groundwater.

Key data gaps were revealed as a result of data gathered during the 2007 study. As presented in this MWH (2008a) report, and consistent with the original conceptual model, the alluvial system is the groundwater flow system most impacted by the mining operations. In addition, the alluvial system represents the most direct contaminant transport route to potential receptors. Because of this, the largest effort in 2008 will be focused on further characterizing the alluvial system.

2.2 PROPOSED 2008 DIRECT-PUSH GROUNDWATER SAMPLING INVESTIGATION

A significant component of the groundwater investigation to be conducted in 2008 will be the direct-push groundwater sampling investigation (MWH, 2008b). This investigation has the potential for providing a large amount of data related to the potential impacts to the shallow alluvial system and will address many data gaps associated with that flow system. For several reasons, the alluvial system may be the most important to evaluate. Most notably, exposure pathways to the alluvial system may be the most direct.

The direct-push groundwater sampling investigation was originally to be implemented in the fall of 2007. However, the drilling program results suggested that water levels in the alluvial system were depressed, and if implemented in the fall, the direct-push program may not be as successful as hoped. Therefore, the program was delayed until the spring of 2008 with the objective of sampling when the water table will be elevated, and thereby, increasing the probability of successfully obtaining samples.

The DDPGS Work Plan was submitted to the Agencies in November 2007, and the Agencies provided comments in December 2007. The Agencies requested some additional areas be sampled and suggested some procedures for hydraulic testing and temporary well installation. P4 responded to these comments and submitted a revised work plan on January 18, 2008. Additional comments were made on the DDPGS Work Plan by the Agencies and P4 responded to them on March 26, 2008. On April 18, 2008 the work plan was approved by the Agencies.

Generally, the direct-push groundwater sampling investigation will evaluate each of the larger alluvial systems at each mine with multiple direct-push sampling locations. The direct-push groundwater sampling investigation will provide a valuable screening-level evaluation of the alluvial flow system.

Analysis of the data will help address data gaps associated with the alluvial systems and locate longer term monitoring points in strategic locations, if needed.

3.0 SCOPE OF WORK – MONITORING WELLS

The scope of work to be performed at the Enoch Valley Mine, Henry Mine, and Ballard Mine sites during the Spring/Summer/Fall of 2008, in support of the on-going groundwater site investigation, consists of the following tasks:

- Drilling and Monitoring Well Installation
- Aquifer Material Testing
- Groundwater Monitoring
- Hydrogeologic Testing
- Monitoring Well Surveying
- Data Submitting

Details of each task are presented in Sections 3.1 to 3.6. Descriptions of the field methods that will be used to conduct this scope of work are included in Section 4.0.

3.1 DRILLING AND MONITORING WELL INSTALLATIONS

Monitoring wells will be installed at Enoch Valley Mine, Henry Mine and Ballard Mine in the approximate locations shown on Drawings 2 and 3. The purpose and rationale for the proposed monitoring well locations and targets are described in more detail in the sections below. Table 3.1 and Table 3.2 are presented at the conclusion of this section to provide summaries of the proposed well installations and construction details, respectively.

3.1.1 Enoch Valley Mine

During the 2008 field season, the most significant activity to evaluate the alluvial flowpath at the Enoch Valley Mine will be the implementation of the Direct-Push Groundwater Sampling Work Plan (MWH, 2008b). This will address data gaps in a number of areas. Four monitoring wells were installed in 2007 to assess groundwater conditions in the alluvial system at Enoch Valley Mine. Three of the monitoring well locations may not address the shallowest portion of the alluvial system, and alluvial groundwater was not encountered in any of the four monitoring locations. To supplement the data from these wells, the direct-push program will be implemented in the spring when the alluvial water levels should be higher. The direct-push program will provide greater spatial coverage.

Drawing 2 shows the locations of the proposed monitoring wells to be installed at the Enoch Valley mine. Drawings 4 through 6 show the subsurface conditions in the vicinity of the proposed monitoring wells.

The shallow portion of the Dinwoody Formation has been demonstrated not to be impacted by selenium in the southern portion of the Enoch Valley Mine. It is in this area that there appears to be the greatest potential for an impact to the Dinwoody Formation based on the amount of waste rock placed on the Dinwoody Formation. The deeper flowpath in the Dinwoody Formation that originates beneath the waste rock pile has not been investigated. Two wells on the southeast (MMW024) and southwest (MMW025) side of the mine will be installed into the Dinwoody Formation to evaluate this flowpath. Similar data has not been developed for the northern end of the mine. However, the amount of waste rock placed on the Dinwoody Formation is much smaller, and based on the reclamation with steeper slopes; the potential for an impact appears much smaller. In the northern portion of the mine, one monitoring well (MMW027) will be installed in the vicinity of MMW012 to monitor the water quality in the Dinwoody Formation.

The most significant component of the Wells Formation regional flow system, from a potential receptor perspective, is flow to the northwest or southeast along the structural grain. On the northwest end, MMW009 helped address this data gap, as well as, flow to the southwest down-dip. To the southeast, one monitoring well, MMW026 will be installed to assess the Wells Formation regional flow system.

Installation of monitoring wells west of the mine is not recommended at this time given the required depth of any wells installed west of the southern and central portions of the Enoch Valley Mine would be over 1,000 feet. In addition, the selenium concentration, 0.001 mg/l, in groundwater collected from MMW009 was less than the groundwater quality standard.

3.1.2 Henry Mine

Impacts to the alluvial system surrounding the Henry Mine have not been observed based on sampling of springs and shallow monitoring wells. However, some areas are not well understood in terms of whether shallow alluvium is present, the local hydrogeologic setting, and how the alluvial system relates to the primary mine features (backfilled pits, open pits, and waste dumps). Therefore, further characterization of the alluvial system has been planned in some areas using geologic reconnaissance and a direct-push sampling program (MWH, 2008b). This program will help better define the location of saturated alluvium, colluvium, and weathered bedrock, and further evaluate whether selenium impacts to the shallow alluvial system have occurred. The direct-push program may include the installation of direct-push pre-packed screens at select locations that can be completed for short-term shallow groundwater monitoring.

The shallow portion of the Dinwoody Formation has been demonstrated to be impacted by selenium near Center Henry. This area has the greatest potential for an impact to the Dinwoody Formation based on the amount of waste rock placed on the Dinwoody Formation, as well as the configuration of the waste dump surface. Only minor amounts of waste rock overlie the Dinwoody Formation in other areas, and in these areas the waste dump surface has better grading to develop positive drainage off the reclamation area. Monitoring well MMW022 is sufficient to monitor impacts to the Dinwoody Formation and additional investigation of the intermediate groundwater system within the formation is not necessary at this time. However, given the orientation of the Dinwoody Formation bedding and the conceptual flow direction away from the mine area toward Lone Pine Creek to the northeast, a further spring survey is planned for the 2008 field season to confirm previous reconnaissance in this area. At present, no monitoring wells are planned to be installed in this area. However, depending on the results of the spring survey, an additional monitoring well may be installed.

The other potential flow direction in the Dinwoody Formation is to the northwest toward the Little Blackfoot River. This potential flow path will be addressed through the installation of a monitoring well (MMW028) into the Dinwoody Formation, near the Little Blackfoot River. Drawing 3 shows the proposed monitoring well location. Drawing 7 shows the subsurface conditions in the vicinity of the proposed monitoring well.

There are no areas where impacts to the Thaynes Formation are likely to occur, as none of the waste dumps or pits are in direct contact or overlie the Thaynes Formation. Furthermore, surface water runoff and shallow groundwater flow cannot impact the Thaynes Formation as it is separated from the mine by intervening ridges and valleys. Therefore, additional investigation of the Thaynes Formation is not required.

The most significant data need associated with the regional flow system in the Wells Formation is surveyed water level data from MMW011 and MMW023 to help validate the conceptual model of flow along strike to the spring near Henry. These data were not obtained before access was limited by snow in 2007. However, these monitoring wells will be surveyed as part of the 2008 survey.

3.1.3 Ballard Mine

Impacts to the alluvial system surrounding the Ballard Mine have been documented through sampling of springs and shallow monitoring wells. Further characterization of the alluvial system has been planned using a direct-push sampling system (MWH, 2008b). This program will help define the extent of selenium impacts in the shallow alluvial system. Once completed, an assessment will need to be made as to locations for possible alluvial monitoring well installations. Further, through the characterization of the alluvial system, monitoring wells in the underlying formations can be located in areas that are more likely to be impacted if downward migration from the alluvium is occurring.

Drawing 3 shows the locations of the proposed monitoring wells to be installed at the Ballard mine. Drawing 8 shows the subsurface conditions in the vicinity of the proposed monitoring wells.

To assess if impacts are occurring due to migration from the alluvium into the Dinwoody Formation, a monitoring well will be installed east of the mine area (MMW029). This monitoring well will be installed into the Dinwoody Formation below the alluvial/bedrock contact in the less decomposed portion of the unit.

The presence of impacted alluvial groundwater west of the mine area and impacted Wells Formation in the mine area suggest that the Wells Formation along the western edge of the mine site should be further investigated. Two areas are proposed for consideration for additional Wells Formation monitoring wells. The first well (MMW030) is in the vicinity of MW-16A. This area is potentially downgradient of MMW006 and near an apparent east-west structure that may direct flow from the southern edge of the mine area. A second well (MMW031) will be installed 1,000 to 1,500 feet north-northeast of MMW0017 to address potential northwestward groundwater flow in the Wells Formation from the mine site along the strike of bedding and structures.

TABLE 3.1
PROPOSED NEW MONITORING WELLS
ENOCH VALLEY, HENRY, AND BALLARD MINES

New Well Identification	Location of New Well	Estimated Total Depth (feet)	Targeted Geology	Primary Purpose
ENOCH VALLEY MINE				
MMW024	Along the south end of Enoch Valley Mine, near MMW013	190	Dinwoody Formation	Monitor water quality in the deeper portion of the Dinwoody Formation that may be impacted by waste rock deposited in the southern portion of the mine.
MMW025	Along the south end of Enoch Valley Mine, near MMW007	170	Dinwoody Formation	Monitor water quality in the deeper portion of the Dinwoody Formation that may be impacted by waste rock deposited in the southern portion of the mine.
MMW026	Northeast of MPW006/MMW008	275	Wells Formation	Monitor water quality and water levels in order to assess potential southeast flow pathway.
MMW027	Near MMW012	150	Dinwoody Formation	Monitor water quality in the Dinwoody Formation for impacts due to waste rock in the northern portion of the mine.
HENRY MINE				
MMW028	Near the Little Blackfoot River northwest of MMW019	50	Dinwoody Formation	Monitor the northwest trending potential flow path on east side of mine area.
BALLARD MINE				
MMW029	East Ballard mine area in the vicinity of MMW018	65	Dinwoody Formation	Monitor water quality in the deeper flow path within the Dinwoody Formation.
MMW030	Along the southwestern portion of Ballard Mine in the vicinity of MMW016A	175	Wells Formation	Monitor possible impacts to the Wells Formation from shallow alluvial flow path.
MMW031	Along the western perimeter of Ballard Mine in the vicinity and north of MMW017	175	Wells Formation	Monitor possible impacts to the Wells Formation from shallow alluvial flow path.

TABLE 3.2 (all depths in feet) WELL CONSTRUCTION DETAILS – NEW BORINGS ENOCH VALLEY, HENRY AND BALLARD MINES - P4 PRODUCTION INC																			
New Well Identification	Location of New Well	Estimated Drilling Depth	Estimated Bottom of Boring	Estimated Bottom of Well	Surface Casing		Well Casing*		Well Screen		10-20 Sand		#60 Sand		Hydrated Bentonite Pellets		Bentonite Slurry	
					Material	Depth from Surface	Material	Depth from Surface	Material	Length	From	To	From	To	From	To	From	To
ENOCH VALLEY MINE																		
MMW024	Along the southeastern end of Enoch Valley Mine, near MMW013	190	190	190	6” Steel	3	4” PVC	160	4” PVC	20	190	165	165	160	160	150	150	0
MMW025	Along the southwestern end of Enoch Valley Mine, near MMW007	150	150	150	6” Steel	3	4” PVC	130	4” PVC	20	150	125	125	120	120	110	110	0
MMW026	Northeast of MPW006/MMW008	250	250	250	6” Steel	3	4” PVC	230	4” PVC	20	250	225	225	220	220	210	210	0
MMW027	Near MMW012	150	150	150	6” Steel	3	4” PVC	130	4” PVC	20	150	125	125	120	120	110	110	0
HENRY MINE																		
MMW028	Near the Little Blackfoot River northwest of MMW003	50	50	50	6” Steel	3	4” PVC	35	4” PVC	15	50	30	30	25	25	15	15	0
BALLARD MINE																		
MMW029	East mine area in the vicinity of MMW018	65	65	65	6” Steel	3	4” PVC	50	4” PVC	15	65	45	45	40	40	30	30	0
MMW030	Along the southwestern portion of Ballard Mine in the vicinity of MMW016A	175	175	175	6” Steel	3	4” PVC	155	4” PVC	20	175	150	150	145	145	135	135	0
MMW031	Along the western perimeter of Ballard Mine in the vicinity and north of MMW017	175	175	175	6” Steel	3	4” PVC	155	4” PVC	20	175	150	150	145	145	135	135	0

*** WELL SCREENS WILL BE 4” PVC VEE-WIRE WRAP CONTINUOUS SLOT**

3.2 AQUIFER MATERIAL TESTING

Aquifer material (soil/rock) samples will be collected from drill cuttings during drilling of borings. Two samples from each boring will be collected. Samples will be selected from the depth interval where water is first encountered in the borehole, and the sample at the bottom of the borehole. Samples will be archived for possible later analyses.

3.3 GROUNDWATER MONITORING

Following well development, all new wells will be sampled either through the traditional 3-casing volume, parameter-stabilization purging method or through use of low flow sampling techniques. Samples will be analyzed for the parameters listed in Table 5.1 (Section 5.0).

3.4 HYDRAULIC CONDUCTIVITY TESTING

Select monitoring wells will be tested for hydraulic conductivities. Monitoring wells less than 150 feet deep will have the hydraulic conductivity of the screened formation tested by using the "slug test" procedure. For selected deeper wells, the feasibility of single well pneumatic slug tests will be evaluated. The following monitoring wells will be tested to assess hydraulic conductivities:

- Enoch Valley Mine – MMW024, MMW026, and MMW027;
- Henry Mine – MMW028;
- Ballard Mine –MMW029 and MMW031.

3.5 MONITORING WELL SURVEY DATA

Following installation of the monitoring wells, the following survey data will be collected at the sites and placed on the topographic maps: horizontal coordinates; elevation of the top of PVC well casing; elevation of the top of the steel surface casing; and approximate ground surface elevations. Monitoring wells not surveyed in 2007 will be included in the 2008 survey. Surveys will be completed by licensed surveyors.

3.6 SUBMITTALS

The following will be prepared and submitted to IDEQ for distribution to the various regulatory agencies:

- Weekly, electronically transmitted, progress reports;
- Boring logs and well construction diagrams;
- Groundwater analytical data;
- Survey data;
- Geologic maps and cross sections.

4.0 FIELD METHODS

This well installation work plan consists of drilling, installation and development of new groundwater monitoring wells; soil and groundwater sampling and analysis; and surveying. The procedures regarding the above listed activities are outlined below, and standard operation procedures (SOPs) for selected activities are included in the Appendix. All sampling activities conducted for this investigation will be in accordance with the Comprehensive Site Investigation Program Field Sampling Plan (PgmFSP) and Quality Assurance Plan (PgmQAP), which were submitted to the agencies in April 2004 (MWH, 2004).

4.1 DRILLING

A Field Engineer/Geologist will supervise the drilling operations. The Field Engineer/Geologist will maintain a drill log noting lithology, sampling interval, and other pertinent information. It is anticipated that samples will be collected approximately every 5 feet (where possible) in the unsaturated and saturated zones from the cuttings. Cuttings are collected for lithologic characterization and analytical testing. All groundwater monitoring wells installed during this investigation will be permitted through the Idaho Department of Water Resources (IDWR) and will be constructed according to their guidelines. A more detailed description of proposed drilling methods is outlined in the Appendix.

4.2 WELL INSTALLATION AND DEVELOPMENT

A Field Engineer/Geologist will monitor all well installation procedures performed by the drilling company and record dates and times of events. In general, wells will be installed by lowering PVC casing down the borehole to specified depths. Screened intervals will be 10, 20 or 40 feet depending on the depth of the hole and purpose. The sand pack will be tremied down hole until the depth is a total of 5 to10 feet above the top of the screened interval. Bentonite pellets will be placed above the sand pack to form at least a 5-foot seal. The rest of the annular space will be grouted with cement/bentonite grout mixture or bentonite slurry. All wells will have surface completions with steel monuments cast into a concrete pad. All surface casings will be fitted with a locking cap and locked with a P4 Production lock.

Once the wells have been installed, the Field Engineer/Geologist will monitor development performed by a pump crew. The goal of monitoring well development is to remove fines and drilling fluid residue from the gravel pack and the natural formation in the vicinity of the screened interval, which will assure good communication between the aquifer and the well. The result of well development is assurance that a sample collected will be a true representative of the quality of water moving through the formation. The well development process is composed of: (1) the application of sufficient energy in a monitoring well to create groundwater flow reversals (surging) in and out of the well and the gravel pack to release and draw fines into the well; and (2) pumping or bailing to draw drilling fluids out of the borehole and adjacent natural formation along with fines that have been surged into the well.

Development will be accomplished by surging and bailing/pumping. A bailer will be used to clean out any fines that have settled on the bottom of the well. Next, a surge block will be used to agitate the water, causing it to move in and out of the screen. This will draw in fines from the gravel pack breaking up any bridges that may have occurred during the placement of the gravel pack. After surging for a few minutes, the bailer will be lowered again to clean out any fines brought into the casing from surging. This cycle will continue until minimal fines are being pulled out with the bailer. At this point, a submersible pump will be lowered down the well. Pumping will begin at a low flow rate and will gradually be increased. The discharge flow rate will be increased (if possible) until the well is pumping at its maximum yield without draw down beneath the pump. Pumping will continue until the water is clear of sediment and field parameters are consistent. A more detailed description of well installation and development is provided in the Appendix.

4.3 AQUIFER MATERIAL TESTING

Aquifer material (soil/rock) samples will be collected from drill cuttings during drilling of the borings. Samples will be selected from the depth interval where water is first encountered in the borehole, and the sample at the bottom of the borehole. Sample material will be double bagged and labeled with the boring location and name, depth interval, date and time, project information and sampler initials. Samples will be archived. All soil samples will be collected as described in the Comprehensive Site Investigation Program Quality Assurance Plan (PgmQAP), which was submitted to the agencies, in April 2004 (MWH, 2004).

4.4 HYDRAULIC CONDUCTIVITY TESTING

Two methods will be used to evaluate the hydraulic conductivities of the aquifer material. The first method will be used to evaluate wells less than 150 feet deep. It consists of introducing a slug (as instantaneously as practicable) of known volume into the well and measuring the response of the water-bearing formation. Either water can be introduced or a solid slug on a rope or cable. With a solid, the response to insertion and withdrawal can be measured. Pneumatic slug testing will be used to evaluate hydraulic conductivities in monitoring wells greater than 150 feet. The principle is the same as the aforementioned method but compressed air is used to depress the water level, thus mimicking the slug. Both methods will be completed by a qualified field engineer/geologist.

4.5 GROUNDWATER SAMPLING

4.5.1 Static Water Level Measurement

Measurement of the static water level (SWL) is performed using either a steel tape or electric probe. The same measuring point on the casing is used to ensure the measurements are consistent. For MWH field studies, the wellhead reference point will be at the top of casing - north side. Static water level measurements will be taken in all new wells before sampling, and in surrounding site wells.

4.5.2 Groundwater Sample Collection

Following well development, all new wells will be purged and sampled either through the traditional 3-casing volume, parameter-stabilization purging method or through use of low flow sampling techniques. All groundwater wells will be sampled as described in the PgmQAP and according to SOP-NW-5.3, Collection of Groundwater Quality Samples, which is located in Appendix B of the PgmQAP (MWH, 2004).

5.0 LABORATORY ANALYSES

Table 5.1 presents the groundwater analytes, associated methods, estimated detection limits (EDL), reporting units, and estimated holding times. Data for the following analytes: aluminum, manganese, iron, nitrate and nitrite will be obtained to further explore the groundwater geochemistry at the mines. ACZ will perform the analyses on the groundwater samples collected from the wells. The University of Idaho Laboratory will perform the analyses on field duplicate samples.

ACZ Laboratories, Inc.
30400 Downhill Drive
Steamboat Springs, CO 80487
Phone: (800) 334-5493

University of Idaho
Holm Research Center
2222 W 6th St
Moscow, ID 83844
Phone: 208-885-7081

Table 5.1 Groundwater Monitoring Analyses				
Parameter	**Method**	**EDL**	**Reporting Units**	**Holding Time (days)**
alkalinity, total	SM2320B	2	mg/L	14
aluminum	M200.7 ICP	0.03	mg/L	180
antimony*	M200.8 ICP/MS	0.0004	mg/L	180
arsenic*	M200.8 ICP/MS	0.0001	mg/L	180
barium*	M200.7 ICP	0.0001	mg/L	180
beryllium*	M200.7 ICP	0.0001	mg/L	180
cadmium	M200.8 ICP/MS	0.0001	mg/L	180
calcium	M200.7 ICP	0.2	mg/L	180
chloride	M300.0	0.5	mg/L	28
chromium*	M200.8 ICP/MS	0.0001	mg/L	180
cobalt*	M200.7 ICP	0.01	mg/L	180
copper*	M200.7 ICP	0.01	mg/L	180
dissolved oxygen (field measurement)				
gross alpha*	M900.0	2	pCi/L	180
gross beta*	M900.0	4	pCi/L	180
hardness	Calculation	1.5	mg/L	-
iron	M200.7 ICP	0.01	mg/L	180
ferrous iron, dissolved (Field)	HACH	0.01	mg/L	-
ferric iron, dissolved	Calculation	0.01	mg/L	-
lead*	M200.8 ICP/MS	0.04	mg/L	180
manganese	M200.8 ICP/MS	0.0005	mg/L	180
magnesium*	M200.7 ICP	0.2	mg/L	180
mercury*	M245.1	0.0002	mg/L	28
molybdenum*	M200.7 ICP	0.01	mg/L	180
nickel	M200.8 ICP/MS	0.0006	mg/L	180
nitrogen (Total nitrate and nitrite)*	M 353.2	0.02	mg/L	28
orthophosphate	M 365.1	0.005	mg/L	28
pH	M150.1	0.1	pH	-
potassium	M200.7 ICP	0.3	mg/L	180
selenium	SM3114 B, AA-Hydride	0.001	mg/L	180
silver*	M200.7 ICP	0.01	mg/L	180
sodium	M200.7 ICP	0.3	mg/L	180
sulfate	M300.0	0.5	mg/L	28
thallium*	M200.8 ICP/MS	0.0001	mg/L	180
total dissolved solids*	M160.1	10	mg/L	7
total suspended solids*	M160.1	10	mg/L	7
uranium*	M200.8 ICP/MS	0.0001	mg/L	180
vanadium	M200.8 ICP/MS	0.0002	mg/L	180
zinc	M200.8 ICP/MS	0.002	mg/L	180

* Analytes included as a screening for one groundwater sampling event.
Methods are for media (non-blank) samples.
Equipment and field blanks will be analyzed for unfiltered results. For regulatory compliance, all media samples will be analyzed for unfiltered metals.
EDL – Estimated Detection Limit; the laboratory analytical limit does not reflect possible sample-specific elevation of the reporting limit due to dilution, contamination or other issues identified during the data validation process.

6.0 SCHEDULE

The following tasks, related to monitoring well installations, will be completed during 2008.

- Drilling and Monitoring Well Installation
- Monitoring Well Surveying – at time of installation
- Groundwater sampling – after well completion
- Data submittal – one month after data validation is completed

7.0 REFERENCES

MWH, 2004. *Comprehensive Site Investigation Program Field Sampling Plan.* Prepared by MWH for P4 Production, Southeast Idaho Mine-Specific Selenium Program, March 2004.

MWH, 2007. *Monitoring Well Installation Technical Memorandum for Final 2005 Phase II Supplemental SI Groundwater Work Plan*. Prepared by MWH for P4 Production, Southeast Idaho Mine-Specific Selenium Program, February 2007.

MWH, 2008a. *Interim Report for Hydrogeologic Investigation-2007 Hydrogeologic Data Collection Activities and Updated Conceptual Models.* Prepared by MWH for P4 Production, Southeast Idaho Mine-Specific Selenium Program, February 2008.

MWH, 2008b. *Draft Direct-Push Groundwater Sampling Work Plan, Ballard, Henry, and Enoch Valley Mines.* Prepared by MWH for P4 Production, Southeast Idaho Mine-Specific Selenium Program, January 2008.

DRAWINGS

APPENDIX A
SOP

Borehole Drilling and Logging
Monitoring Well Installation
Aquifer Testing

Standard Operating Procedures

June 2008

Prepared by:

MWH

2353 130th Avenue N.E., Suite 200
Bellevue, Washington 98005

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LIST OF ATTACHMENTS

1.0 INTRODUCTION

The purpose of this document is to define the standard procedures for drilling, logging, testing, documentation, and installation of boreholes and monitoring wells. This SOP provides descriptions of equipment, field procedures, and technical procedures necessary to perform the proposed drilling and sampling activity. The procedures described herein are intended to be used with other applicable SOPs, as appropriate.

This SOP describes procedures for conducting the tasks listed below.

- Drilling boreholes
- Sampling soil for lithologic description
- Borehole logging
- Equipment decontamination
- Well design and construction
- Well development
- Aquifer testing (slug testing)

Many terms included in this SOP may be unfamiliar to the reader. A glossary of terms is included in Attachment A.

2.0 DRILLING OPERATIONS

Drilling methods can be separated into two general types - techniques that do not use circulating fluids and techniques that use circulating fluids. The following sections discuss the drilling methods that fall into each of these two general categories that are most likely to be used for this project.

This section provides a description of the principles of operation and the applicability and implementability of the drilling methods that are proposed for this investigation. It focuses on methods and equipment that are readily available and typically applied. It is not intended to provide an all-inclusive discussion of drilling methods. Drilling will be conducted using air rotary drilling rigs, hollow stem auger (HSA) drilling rigs, and Rotasonic drilling rigs. Other alternatives that will be available are dual-tube percussion hammer and Rotary-sonic drilling. These methods are discussed below. All drillers and drilling personnel working onsite will be 40 hour OSHA (CFR 1910) certified and 24 hour MSHA certified. Drillers will also be available to provide additional services for minor repair or servicing of existing wells.

2.1 DRILLING METHODS WITHOUT CIRCULATING FLUIDS

2.1.1 HOLLOW-STEM AUGER DRILLING

Drilling is accomplished by rotating a pipe or rod that has a cutting bit. The common auger drilling method expected to be used is discussed in section.

Hollow-stem augers (H.S.A.) are commonly used in unconsolidated materials up to 150 feet in depth. A key advantage of H.S.A. drilling is that undisturbed soil samples can be collected through the auger, which acts as a temporary outer casing during drilling. The auger also acts as a temporary outer casing during monitoring well installation.

Hollow-stem augers consist of two parts: a tube with flights attached to the outside and connected the lead auger, and an inner pilot or center rod and bit which is removable from the center of the auger. The removable inner plug is the primary advantage of this drilling method. Withdrawing the plug while leaving the auger in place provides an open, cased hole into which soil samplers, down-hole drive hammers, instruments, casing, wire, pipe, or numerous other items can be inserted. Replacing the center bit and plug allows for continuation of the borehole.

Hollow-stem augers are specified by the inside diameter of the hollow stem, not by the hole size it drills. Hollow-stem augers are available in a variety of diameters, such as 2.5, 3.25, 3.375, 4.0, 4.25, 6.25, 6.625, 8.25, and 10.25 inches. The most commonly used sizes are 3.25 inches and 4.25 inches for soil borings that may be completed as 2-inch monitoring wells, and 6.625 inches for soil borings that may be completed as 4-inch monitoring wells.

The rotation of the augers causes the cuttings to move upward and be "smeared" along the borehole walls. This smearing may effectively seal off the upper zones thereby reducing the possibility of cross contamination of the upper zones to the deeper zones but increases the possibility of deep to shallow contamination. Conversely, smearing of clays on the borehole walls may seal off aquifers to be monitored.

Applications

- Suitable for all types of soil investigations.
- Allows good soil sampling with split-spoon samplers or Shelby tubes.
- Monitoring well installation in all unconsolidated formations.
- Can serve as temporary casing.
- Can be used in stable formations to set surface casing.

Limitations

- Difficulty in preserving sample integrity in heaving formations.
- Formation invasion by water or drilling mud if used to control heaving.
- Possible cross contamination of aquifers where annular space not positively controlled by water or drilling mud or surface casing.
- Limited diameter of augers limits casing size.
- Smearing of clays may seal off aquifer to be monitored.

2.1.2 ROTARY-SONIC DRILLING

Rotasonic drilling is a dual-cased drilling system that uses high frequency vibration to take continuous core samples and advance casing into the ground. The hydraulically powered drill head applies vibration to the drill string. This energy is directed down the drill string to the face of the core bit. No mud pump or air compressor is used to force cutting away from the borehole. The inner core barrel is advanced in increments into the formation, and then the outer casing is advanced down over the core barrel. The core barrel is then removed and the sample extruded into a plastic sleeve.

Applications

- Suitable for all types of soil investigations.
- Allows undisturbed soil sampling and recovery with continuous coring.
- Monitoring well installation in all unconsolidated formations.
- Waste minimization.
- Prevents cross contamination and formation mixing.

Limitations

- Slower through hard dense formations.
- Large rig and requires a support vehicle.
- Technique can create high heat, which is a concern if sampling for hydrocarbons.
- Technique is not appropriate for dense, consolidated material (rock).

2.2 DRILLING METHODS WITH CIRCULATING FLUIDS

Many drilling techniques use a circulating fluid, such as water, drilling mud, air, a combination of air and water, or even a surfactant to create foam. Circulation fluids flow from the surface either through the drill pipe, out through the bit, and up the annulus between the borehole wall and the drill pipe (direct rotary) or down the borehole annulus, into the bit, and up the drill pipe (reverse rotary). Generally the up-hole velocity needed to transport cuttings to the surface is between 100 to 150 feet per minute for plain water with no additives, 80 to 120 feet per minute for high-grade bentonite drill muds, 50 to 1,000 feet per minute for foam drilling, and up to 3,000 feet per minute for air with no additives. Additives decrease the required minimum velocity. Excessive velocities can cause erosion of the borehole wall. For this project, air is the expected fluid.

The use of circulating fluids may involve the addition of chemicals to the borehole. Drilling mud utilizes bentonite clay or polymers. Additives to air drilling may include surfactants (detergents) and water mist to generate foam. Compressed air may also contain various amounts of hydrocarbon lubricants. Therefore, attention should be given to the circulating fluids and any possible additives that are used when using drilling methods utilizing circulation fluids.

2.2.1 DUAL-TUBE REVERSE ROTARY DRILLING

This method is a specialized rotary or percussion drill that uses a double-walled tubular drill rod. The circulation drilling media, compressed air or air-foam, is forced downhole through the annulus between the inner and outer rod wall. For a reverse-circulation rotary drill, the circulation media is ejected near the tool joint connection between the rotary bit and the center rod. The media circulates around the outside face of the bit to cool the bit and moves drill cuttings upward through a center opening in the bit. The cuttings are forced up the center tube to a discharge point at the hole collar. For a reverse-circulation percussion drill, the circulation media is ejected just above the drive shoe on the outer rod. The circulation media forces drill cuttings in the drive shoe upward through the center tube to a discharge point at the hole collar.

Applications & Advantages

- Drilling through loss circulation zones (loose sands, voids, etc.) for recovering uncontaminated disturbed samples and for testing water.
- Drilling through gravel to boulder-size material and for recovering uncontaminated disturbed samples of sand, gravel, and cobble-size material.
- Drilling deeper depths
- The drive pipe can be used as a temporary casing through the coarse aggregate deposits.

Limitations

- Difficult to obtain accurate sampling below the water table

2.2.2 AIR ROTARY DOWN-THE-HOLE HAMMER

This method combines percussion and air rotary drilling methods to drill. The borehole is drilled using the air rotary drilling method. A pneumatic drill, "down-the-hole", at the end of the drill pipe strikes the rock while the drill pipe is gradually rotated. Rotation helps to insure even penetration. The air used to run the drill is used to remove cuttings. Casing or drive pipe follows closely behind the rotary bit to prevent the erosion of the borehole wall.

Applications & Advantages

- Rapid drilling of unconsolidated sands, silts, and clays.
- Drilling in alluvial materials (including boulder formations).
- Casing supports borehole thereby maintaining borehole integrity and minimizing inter-aquifer cross contamination.
- Eliminates circulation problems common with direct mud rotary method.
- Good formation samples for stratigraphic evaluation.
- Minimal formation damage as casing is pulled back.

Limitations

- Thin, low pressure water bearing zones easily overlooked if drilling is not stopped at appropriate places to observe whether or not water levels are recovering.
- Samples pulverized as in all rotary drilling.
- Air may modify chemical or biological conditions.
- Difficult to obtain soil samples for chemical analysis.

2.3 PERMITTING

All monitoring wells and piezometers proposed to be installed will be installed and constructed in accordance with all applicable Idaho Department of Water Resources (IDWR) rules and regulations. For each monitoring well a permit to drill, deepen, replace, or modify a Monitoring Well must be filed with IDWR prior to the start of drilling.

A licensed drilling subcontractor registered with IDWR will conduct all drilling and well installation activities.

2.4 SAMPLING METHODS

2.4.1 Lithologic Sampling

A Field Engineer/Geologist will maintain a drill log noting lithology, sampling interval, and other pertinent information. It is anticipated that samples will be collected approximately every 5 feet (where possible) from the cuttings. Cuttings are collected for lithologic characterization and analytical testing and are placed in specially-designed “chip-tray” plastic containers. All groundwater monitoring wells installed during this investigation will be permitted through the Idaho Department of Water Resources (IDWR) and will be constructed according to their guidelines. More details in lithologic logging can be seen in section 3.0 and a copy of the litholgic sampling form is presented in Attachment B.

2.5 BOREHOLE OR WELL ABANDONMENT

Any borehole that will not be converted into a well (e.g., soil borings, bedrock boreholes) will be abandoned according to all applicable IDWR rules and regulations. The borehole will be abandoned by pumping cement-bentonite grout to the bottom of the borehole through a tremie pipe until the borehole is filled to the ground surface with undiluted grout. Dry holes less than 15 feet deep can be filled with grout poured from the surface. After 24 hours, the abandoned borehole will be checked for grout settlement. Any settlement will be filled in with grout, using a tremie pipe if it is deeper than 15 feet. This process will be continued until firm grout remains at the ground surface. Under no circumstances, will the borehole be backfilled with the soil removed during drilling and sampling operations.

There are currently no monitoring wells slated for abandonment during this SCP. However, if circumstances develop where a monitoring well needs to be abandoned, the well will be abandoned according to IDWR regulations, and the proper forms will need to be filed with IDWR prior to commencement of abandonment procedures.

2.6 DRILLING EQUIPMENT DECONTAMINATION

The purpose of decontamination and cleaning procedures during excavation, drilling and sampling is to prevent contamination of the samples and cross-contamination between sites. A decontamination area and clean zone will be established for the preparation and breakdown of equipment prior to each sampling task. The decontamination area will be large enough to accommodate equipment to be used for invasive work and that will allow decontamination rinsate to be pumped off for temporary storage and subsequent disposal. Before use and between each site, all equipment and other non-sampling equipment will be decontaminated with high-pressure steam, or scrubbed with a non-phosphate detergent and rinsed with water from an approved water source. If appropriate, equipment will be covered in plastic to protect it from the elements.

All equipment that may directly contact samples, such as split-spoon samples or core barrels, will be decontaminated on-site. The following sampling-specific decontamination procedures will be utilized.

- Wash and scrub with detergent (laboratory grade, non-phosphate detergent)
- Rinse with potable water
- Rinse with deionized water
- Rinse with another batch of deionized water
- Air dry
- Protect from fugitive dust and vapors

3.0 BOREHOLE LOGGING - SOILS

3.1 GENERAL

The procedures described herein are applicable to logging soils and are based on the Unified Soils Classification System (USCS); ASTM Standard D 2488-93, Standard Practice for Description and Identification of Soils (Visual Manual); and ASTM Standard D 5434-93, Standard Guide for Field Logging of Subsurface Explorations of Soil and Rock (ASTM, 1993).

Much of the information described in this section is summarized on several tables and in a USCS field guide, as shown in Attachment C. Other field guidance references also may be used according to personal preference; however, such references must be based on the USCS. Note that many references (for example, AGI Data Sheet grain size scales) are base soil classifications on the Wentworth Scale. Such scales may vary significantly from the USCS and will lead to inaccurate or inconsistent soil descriptions.

All soil logging will be documented using the *Soil Boring Log Form* included in Attachment D.

3.2 GEOLOGIST/HYDROGEOLOGIST

One or more geologists or hydrogeologist will accompany each operating drill rig for inspection of drilling and borehole testing work. Each individual will be responsible for only one operating rig. Once assigned to an individual borehole, that person will remain as the geologist or hydrogeologist until that borehole is completed, unless approved for replacement. The geologist or hydrogeologist will be present during the entire time that the drill rig is operating and during casing and screen installation, developing and clean-out operations.

The geologist or hydrogeologist will observe and record the drilling operations along with the characteristics of the subsurface materials. This individual will be responsible for the preparation of a separate log for each boring and will sign each log.

3.3 DEFINITIONS

Use of the USCS requires familiarity with the grain size ranges that define a particular type of soil, as well as several other physical characteristics. The grain size definitions and physical characteristics upon which soil descriptions are based are presented below.

3.3.1 GRAIN SIZES

USCS grain sizes are based on U.S. standard sieve sizes, which are listed below.

- Standard sieves with larger openings are named according to the size of the openings in the sieve mesh. For example, a "3-in." sieve contains openings that are 3 inches square.
- Standard sieves with smaller openings are given numbered designations that indicate the number of openings per inch. For example, a "No. 4" sieve contains 4 openings per inch.

The following grain size definitions are paraphrased from the ASTM Standard D 2488-93. Field personnel should familiarize themselves with the grain size definitions.

Boulders - Particles of rock that will not pass a 12-in. (300-mm) square opening.

Cobbles - Particles of rock that will pass a 12-in. (300-mm) square opening and be retained on a 3-in. (75-mm) sieve.

Gravel - Particles of rock that will pass a 3-in. (75-mm) sieve and be retained on a No. 4 (4.75-mm) sieve with the following subdivisions:

- *Coarse Gravel* - passes a 3-in. (75-mm) sieve and is retained on a 3/4-in. (19-mm) sieve
- *Fine Gravel* - passes a 3/4-in. (19-mm) sieve and is retained on a No. 4 (4.75-mm) sieve

Sand - Particles of rock that will pass a No. 4 (0.19 in. or 4.75-mm) sieve and be retained on a No. 200 (0.003 in. or 75-µm) sieve with the following subdivisions:

- *Coarse Sand* - passes a No. 4 (0.19 in. or 4.75-mm) sieve and is retained on a No. 10 (0.08 in. or 2-mm) sieve
- *Medium Sand* - passes a No. 10 (0.08 in. or 2-mm) sieve and is retained on a No. 40 (0.017 in. or 425-µm) sieve
- *Fine Sand* - passes a No. 40 (0.017 in. or 425-µm) sieve and is retained on a No. 200 (0.003 in. or 75-µm) sieve

Silt - Soil passing a No. 200 (0.003 in. or 75-µm) sieve that is nonplastic or very slightly plastic and that exhibits little or no strength when air-dried. Individual silt particles are not visible to the naked eye.

Clay - Soil passing a No. 200 (0.003 in. or 75-µm) sieve that can be made to exhibit plasticity within a range of water contents and that exhibits considerable strength when air-dried. Individual clay particles are not visible to the naked eye.

3.3.2 PHYSICAL CHARACTERISTICS

The following physical characteristics are used in the USCS classification for fine-grained soils. A brief definition of each physical characteristic is presented below. A determination of the type of fine-grained soil present in the sample can generally be made on the basis of plasticity, as described in Section 3.4.1.2.

Dry Strength - The ease with which a dry lump of soil crushes between the fingers.

Dilatancy Reaction - The speed with which water appears in a moist pat of soil when shaking in the hand and disappears while squeezing.

Toughness - The strength of a soil, moistened near its plastic limit, when rolled into a 1/8-inch diameter thread.

Plasticity - The extent to which a soil may be rolled into a 1/8-inch thread and re-rolled when drier than the plastic limit.

3.4 SOIL LOGGING PROCEDURES

The following aspects of a project must be understood before sampling and soil logging commences.

- Purpose of the soil logging (e.g., initial investigation, subsequent investigation, remediation)
- Known or anticipated hydrogeologic setting including presence of fill material, lithology, physical characteristics of the aquifer, type of aquifer, recharge/discharge conditions, aquifer thickness and ground water/conditions
- Drilling conditions
- Previous soil boring or borehole geophysical logs

- Soil sampling and geotechnical testing program
- Characteristics of potential chemical release(s) (chemistry, density, viscosity, reactivity and concentration)
- Health and Safety protection requirements
- Regulatory requirements

The procedures used to determine the correct soil sample classification are described below. These procedures are presented in Attachment C.

The soils should be described in terms of lithologic units, rather than on a sample-by-sample basis. Thus, a single description may cover several sample intervals, or conversely, several units may occur within a single sample interval. For a specific unit, the primary classification is described and then variations or minor changes are noted below the main description at the depth where they occur.

3.4.1 FIELD CLASSIFICATION OF SOILS

When naming soils, the proper USCS soil group name is given followed by the group symbol. For clarity, it is recommended that the group symbol be placed in parentheses after the written soil group name.

Soil identification using the visual-manual procedures is based on naming the portion of the soil sample that will pass a 3-in. (75-mm) sieve. Therefore, before classifying a soil, any particles larger than 3 inches (cobbles and boulders) should be removed, if possible. Estimate and note the percentage of cobbles and boulders.

Using the remaining soil, the next step of the procedure is to estimate the percentages by dry weight of the gravel, sand and fine fractions (particles passing a No. 200 sieve). The percentages shall be estimated to the closest 5%. In general, the soil is *fine-grained* (e.g., a silt or a clay) if it contains 50% or more fines and *coarse-grained* (e.g., a sand or a gravel) if it contains less than 50% fines. If one of the components is present but estimated to be less than 5%, its presence is indicated by the term *trace*. For example, "trace of fines" would be added as additional information following the formal USCS soil description.

3.4.1.1 Procedure for Identifying Coarse-Grained Soils (contain less than 50% fines)

If it has been determined that the soil contains less than 50% fines, the soil is a *gravel* if the percentage of gravel is estimated to be more than the percentage of sand. The soil is a *sand* if the percentage of gravel is estimated to be equal to or less than the percentage of sand.

If the soil is predominantly sand or gravel but contains an estimated 15% or more of the other coarse-grained constituent, the words "with gravel" or "with sand" shall be added to the group name. For example: "gravel with sand (GP)." If the sample contains any cobbles or boulders, the words "with cobbles" or "with cobbles and boulders" shall be added to group name. For example: "silty gravel with cobbles (GM)."

<u>5% or less fines.</u> The soil is a "clean gravel" or "clean sand" if the percentage of fines is estimated to be 5% or less. "Clean" is not a formal USCS name but rather a general descriptor for implying little to no fines. Clean sands and gravels are given the USCS designation as either *well-graded* or *poorly-graded*, as described below.

Identify the soil as a *well-graded gravel* (GW) or as a *well-graded sand* (SW), if it has a wide range of particle sizes and substantial amounts of the intermediate particle sizes. Identify the soil as a *poorly-graded gravel* (GP) or as a *poorly-graded sand* (SP) if it consists predominantly of one grain size (uniformly graded) or has a wide range of sizes with some intermediate sizes obviously missing (gap- or skip-graded).

Note: When using the USCS, keep in mind the difference between grading and sorting. The term grading is used to indicate the range of particles contained in the sample. For example, a poorly-graded sand containing predominantly one grain size would be considered well-sorted and vice-versa. One notable exception to this general rule is a skip-graded (bimodally distributed) sample: a sand containing two distinct grain sizes would be considered both poorly-sorted and poorly-graded. The USCS uses only the *GRADING* descriptor in soil naming, not the sorting descriptor.

≥ 15% fines. The soil is a *silty* or *clayey gravel* or a *silty* or *clayey sand* if the percentage of fines is estimated to be 15% or more. For example, identify the soil as *clayey gravel* (GC) or a *clayey sand* (SC) if the fines are clayey. Identify the soil as a *silty gravel* (GM) or a *silty sand* (SM) if the fines are silty. The coarse-grained descriptor "poorly-graded" or "well-graded" is not included in the soil name, but rather, should be included as additional information following the formal USCS soil description.

>5% but <15% fines. If the soil is estimated to contain greater than 5% and less than 15% fines, give the soil a dual identification using two group symbols. The first group symbol shall correspond to a clean gravel or sand (GW, GP, SW, SP) and the second symbol shall correspond to a clayey/silty gravel or sand (GC, GM, SC, SM). The group name shall correspond to the first group symbol and include the words "poorly-graded" or "well-graded", plus the words "with clay" or "with silt" to indicate the character of the fines. For example, "poorly-graded gravel with silt (GP-GM)".

3.4.1.2 Procedure for Identifying Fine-Grained Soils (contain 50% or more fines)

The USCS classifies inorganic fine-grained soils according to their degree of plasticity (no or low plasticity - indicated with an "L", or high plasticity - indicated with an "H”). The field tests used to determine dry strength, dilatancy and toughness are generally too time consuming to be performed on a routine basis. Field personnel should be familiar with the definitions of the physical characteristics and the concepts of the field tests; however, field classifications will generally be based primarily on plasticity, as described in Attachment E.

Lean clay (CL) - soil has medium to high dry strength, no or slow dilatancy and medium toughness and plasticity.

Fat clay (CH) - soil has high to very high dry strength, no dilatancy and high toughness and plasticity.

Silt (ML) - the soil has no to low dry strength, slow to rapid dilatancy and low toughness and plasticity, or is nonplastic.

Elastic silt (MH) - the soil has low to medium dry strength, no to slow dilatancy and low to medium toughness and plasticity; will air dry more quickly than lean clay and have a smooth, silky feel when dry.

Organic soil (OL or OH) - the soil contains enough organic particles to influence the soil properties. Organic soils usually have a dark brown to black color and may have an organic odor. Often, organic soils will change color, for example, from black to brown, when exposed to the air. Organic soils normally will not have a high toughness or plasticity.

Other Modifiers for Use with Fine-Grained Soils:

15% to 25% coarse-grained material. If the soil is estimated to have 15% to 25% sand or gravel, or both, the words "with sand" or "with gravel" (whichever is predominant) shall be added to the group name. For example: "lean clay with sand (CL)" or "silt with gravel (ML)." If the percentage of sand is equal to the percentage of gravel, use "with sand."

≥30% coarse-grained material. If the soil is estimated to have 30% or more sand or gravel, or both, the words "sandy" or "gravelly" shall be added to the group name. Add the word "sandy" if there appears to be the same or more sand than gravel. Add the word "gravelly" if there appears to be more gravel than sand. For example: "sandy silt (ML)", or "gravelly fat clay (CH)."

3.4.1.3 Procedure for Identifying Borderline Soils

To indicate that the soil may fall into one of two possible basic groups, a borderline symbol may be used with the two symbols separated by a slash. For example, a soil containing an estimated 50% silt and 50% fine grained sand may be assigned a borderline symbol "SM/ML." Borderline symbols should not be used indiscriminately. Every effort should be made to first place the soil into a single group and then to estimate percentages following the USCS soil description.

3.4.2 DESCRIPTIVE INFORMATION FOR SOILS

After the soil name and symbol are assigned, the soil color, consistency/density and moisture content shall be described in that order. Other information is presented later in the description, as applicable.

3.4.2.1 Color

Describe the color using the Munsell Soil Color Chart (1992). Color is an important property in identifying organic soils and may also be useful in identifying materials of similar geologic or depositional origin in a given location.

When using the Munsell Soil Color Charts, first attempt to assign the soil a general color, such as brown, gray, red, etc. Then go to the correct area in the charts and assign the applicable color name and Munsell symbol. The ability to detect minor color differences varies among people and the chance of finding a perfect color match in the charts is rare. Keeping this in mind should help field personnel avoid spending unnecessary time and confusion going through the chart pages. In addition, attempting to describe detail beyond the reasonable accuracy of field observations could lead to making poorer soil descriptions than by expressing the dominant colors simply (Munsell Soil Color Chart, 1992).

If the color charts are not being used or are unavailable, again attempt to assign general colors to soils. Comparing a particular soil sample to samples from different locations in the borehole will help keep the eye "calibrated." For example, by holding two soils together, it may become evident that one is obviously greenish-brown, while another is reddish.

3.4.2.2 Consistency & Density

For intact fine-grained soil, describe consistency as very soft, soft, medium stiff, stiff, very stiff, or hard, based on the blows per foot using a 140-pound hammer dropped 30", as described in Attachment F. If blow counts are not available, use the thumb test, as described in Attachment F to determine consistency.

For coarse-grained soils, describe density based on blows per foot as very loose, loose, medium dense, dense and very dense, as described in Attachment F. If blow counts are not available, attempt to estimate the soil density by observation, since a practical field test is not available. Be sure to clearly indicate on the field boring log if blow counts could not be obtained.

3.4.2.3 Moisture

Describe the moisture condition of the soil as dry (absence of moisture, dusty, dry to the touch), moist (damp but no visible water, even in interstices) or wet (visible free water, saturated).

3.4.2.4 Maximum Grain Size

Describe the maximum particle size found in the sample in accordance with the information listed below.

- **Sand Size -** If the maximum particle size is a sand size, describe as fine, medium, or coarse.
- **Gravel Size -** If the maximum particle size is a gravel size, describe the diameter of the maximum particle size in inches.
- **Cobble or Boulder Size -** If the maximum particle size is a cobble or boulder size, describe the maximum dimension of the largest particle.

For gravel and sand components, describe the range of particle sizes within each component. For example, "about 20% fine to coarse gravel, about 40% fine to coarse sand."

3.4.2.5 Odor

Due to health and safety concerns, <u>NEVER</u> intentionally smell the soil. This could result in exposure to volatile contaminants that may be present in the soil. If, however, an odor is incidentally noticed, it should be described if organic or unusual. Soils containing a significant amount of organic material usually have a distinctive odor of decaying vegetation (sometimes a hydrogen sulfide ["rotten egg"] smell). If the odor is unusual (petroleum product, chemical, etc.), it should be described. Organic vapor readings from an OVM or similar instrument should be noted on the field boring log. The project-specific Heath and Safety Plan should then be consulted to determine the appropriate level of protection necessary for the continuation of fieldwork.

3.4.2.6 Cementation

Describe the cementation of intact coarse-grained soils as weak, moderate or strong, in accordance with the criteria listed below.

- **Weak -** Crumbles or breaks with handling or little finger pressure
- **Moderate -** Crumbles or breaks with considerable finger pressure
- **Strong -** Will not crumble or break with finger pressure

The presence of calcium carbonate may be confirmed on the basis of effervescence with dilute hydrochloric acid, HCl, if calcium carbonate or caliche is believed to be present in the soil. Proper health and safety precautions must be followed when mixing, handling, storing, or transporting HCl.

3.4.2.7 Angularity

Describe the angularity of the sand (coarse sizes only), gravel, cobbles and boulders, as angular, subangular, subrounded, or rounded in accordance with the criteria listed below.

- **Angular -** Particles have sharp edges and relatively planar sides with unpolished surfaces
- **Subangular -** Particles are similar to angular description but have rounded edges
- **Subrounded -** Particles have nearly plane sides but have well-rounded corners and edges
- **Rounded -** Particles have smoothly curved sides and no edges

A range of angularity may be stated, such as "subrounded to rounded".

3.4.2.8 Structure

Describe the structure of intact soils in accordance with the criteria in Attachment G.

3.4.2.9 Lithology

Describe the primary lithologies (rock or mineral type) of the sand, gravel, cobbles and boulders, if possible. It may be difficult to determine the lithology of fine and medium-grained sand or particles that have undergone alteration.

3.4.2.10 Additional Comments

Additional comments may include the presence of roots or other vegetation, fossils or organic debris, staining, mottling, or oxidation; difficulty in drilling and caving or sloughing of the borehole walls. Also, when drilling in an area known or suspected to contain imported fill material, every effort should be made to identify the contact between fill and native soils. If a soil is suspected to be fill, this should be clearly indicated on the log following the soil description. Stratigraphic units and their contacts should be noted wherever possible.

3.4.3 Additional Boring Log Information

In addition to soil descriptions, there are several other items that should be included on all *soil boring log forms*, included in Attachment D. Information in the log heading should be complete and accurate. The information listed below should be included, at a minimum.

- Boring or monitoring well number
- Project name and job number
- Site name
- Name of individual who logged the boring
- Drilling contractor
- Drill rig type and method of drilling (for example, "CME 75, hollow stem auger")
- Name of drilling company
- Name of driller and helper
- Borehole diameter and drill bit type
- Type of soil sampler (for example, Modified California, continuous core, etc.)
- Time and date that drilling started and finished
- Time and date that the well was completed or the soil boring backfilled, as appropriate
- Method of borehole abandonment, if applicable
- Sketch map of boring or well location with estimated distances to major site features such as property lines or buildings and north arrow

Soil sample information should include the depth interval that was sampled, the blow counts per six inches, the amount of soil recovered and the portion submitted for analysis or testing, if any. The sample identification number may also be noted on the log.

The degree to which soil samples are collected during a field effort depends on the overall scope and purpose of the investigation, which should be clearly defined before the field effort commences. Additional soil samples may need to be collected if, for example, soils are very heterogeneous or unexpected conditions such as perched water zones or zones of contamination are encountered.

If groundwater is encountered during drilling, the depth to water and the time and date of the observation should be recorded. If the first water encountered is a perched zone, the depth, time and date that any additional groundwater zones are encountered should also be recorded. Depth to water after drilling, the measuring point and the date and time of the measurement(s) must be noted. Additional measurements of depth to groundwater, including depth and time, may be beneficial.

4.0 MONITORING WELL DESIGN AND INSTALLATION

4.1 GENERAL

This guideline is applicable to the design and installation of permanent monitoring wells at CC. Each monitoring well will be designed to suit the hydrogeologic setting of the site, the type of contaminants to be monitored, the overall purpose of the monitoring program and other site-specific variables. During all phases of well design, attention must be given to clear documentation of the basis for design decisions, the details of well construction and the materials to be used. A *Typical Monitoring Well Installation Diagram* is provided as Attachment H and a *Monitoring Well Construction Form* is provided in Attachment I.

4.2 WELL LOCATIONS

The current scope of work entails installing 6 monitoring wells. The locations and rationale of these wells are discussed in the Work Plan. These wells are located as single wells.

4.3 WELL DESIGN

4.3.1 CASING DIAMETER AND SCREEN LENGTH

Monitoring well casing diameter is dependent on the purpose of the well and the amount and size of downhole equipment that must be accommodated. All of the wells are designed to be multipurpose monitoring wells. Therefore, they will all be constructed with 6-inch or 8-inch diameter PVC well casing.

With the exception of any wells specifically designed for accommodating a pumping test, the screen lengths will be 10 feet. Any wells that will be screened near the water table will be screened across the water table. Consideration should be given to seasonal fluctuations in water levels when locating the well screen across the top of the water table.

4.3.2 CASING AND SCREEN MATERIALS

The two most commonly used materials are PVC and stainless steel. PVC is inexpensive, widely available, lightweight and easy to work with. Many studies have been conducted concerning the effect of PVC on water quality data. Adsorption of some chlorinated species to PVC was found to be too slow to affect data quality. Because a sample is generally taken shortly after the purging of stagnant water in contact with the casing, the contaminants in the water will have minimal time to be influenced by sorption or leaching effects. Therefore, potential sample bias effects due to interactions with PVC are negligible (Reynolds, et al, 1990). Consequently, monitoring well casings and screens will be constructed of polyvinyl chloride (PVC). Wells less than 150 feet deep will be constructed of schedule 40 PVC, while deeper wells will be constructed of schedule 80 PVC.

The hydraulic efficiency of a well screen depends primarily upon the amount of open area available per unit length of screen. The two screen types commonly used for monitoring wells are machine-slotted and continuous-slot wire-wound. The continuous-slot, wire-wound screen has a greater area per opening per length and diameter than is available with any other screen type. The percentage of open area in continuous-slot screen is often more than twice that provided by standard slotted well screen. The triangular shaped wire makes these screens non-clogging. The monitoring wells installed at the site will be constructed with machine-slotted PVC screens, except ones installed for conducting pumping tests, which may be installed with continuous-slot wire-wound PVC screen.

Additional construction specifications are listed below.

- Threaded, flush-joint casing
- Well caps that are vented to prevent the accumulation of gases and to allow water levels in the well to respond to barometric and hydraulic pressure changes
- Threaded end-caps

4.3.3 DECONTAMINATION OF CASING AND SCREEN MATERIALS

During the production of PVC casing, a wax layer can develop on the inner wall of the casing; protective coatings may also be added to enhance casing durability. All of these represent potential sources of chemical interference and must be removed with either a laboratory-grade non-phosphate solution or by steam cleaning prior to installation. Factory cleaning of casing and screen in a controlled environment by standard detergent washing, rinsing and air-drying procedures is superior to any cleaning efforts attempted in the field. Factory cleaned and sealed casing and screen that is certified by the supplier will be used if available.

4.3.4 FILTER PACK AND WELL SCREEN DESIGN

A properly designed monitoring well requires that a well screen be placed opposite the zone to be monitored and be surrounded by materials that are coarser and of greater hydraulic conductivity than the natural formation material. Filter packs are installed to create a permeable envelope around the well screen. The selection of the filter pack grain size should be based on the grain size of the finest layer to be screened.

The typical well construction for a monitoring well in average formation materials includes filter pack on the order of #3 Monterey sand size and 0.020 inch slotted screen. A configuration similar to this will be used, unless the materials encountered are radically different than expected. The design of wells to be used for pumping during a pumping test is described in Section 10.2.4.

If conditions warrant, filter pack grain size and well screen slot size should be determined by the grain size distribution of the formation material. The filter pack should be designed first. It is recommended to use a filter pack grain size that is three to five times the average (D50) size of the formation materials. D50 will be estimated based on the lithologic description made by the site geologist or hydrogeologist. However, this method may be misleading in coarse, well graded formation materials. Another way to determine filter pack grain size is to take the D30 grain size of the formation materials and multiplying it by a factor of between 3 and 6, with 3 used if the formation is fine and uniform and 6 used if the formation is coarse and non-uniform. For both methods, the uniformity coefficient of the filter pack materials should be as close to 1.0 as possible to minimize particle size segregation during filter pack installation.

The filter pack will extend from the bottom of the well screen to approximately 3 to 5 feet above the top of the screen to account for settlement of the pack material during development and to act as a buffer between the well screen and the annular seal. Filter pack thickness must be sufficient to surround the well screen but thin enough to minimize resistance to the flow of fine-grained formation material and water into the well during development. Consequently, a filter pack thickness of approximately 2 inches will be used.

The materials comprising the filter pack should be as chemically inert as possible. It should be comprised of clean quartz sand or glass beads. Filter pack materials usually come in 100-pound bags; these materials are washed, dried and factory packaged.

The size of well intake openings can only be selected after the filter-pack grain size is specified. The slot size should be such that 90 percent to 100 percent of the filter-pack material is held back by the well screen.

The casing string should be installed in the center of the borehole. This will allow the filter-pack materials to evenly fill the annular space around the screen and ensure that annular seal materials fill the annular space evenly around the casing. Where a dual-tube rig is used, the inner tube of the dual tube will adequately centralize the casing string. For other types of drilling, centralizers will be used to ensure the casing string is positioned in the center of the borehole. Centralizers are typically expandable metal or plastic that attach to the outside of the casing and are adjustable along the length of the casing. Centralizers will be attached immediately above the well screen and at 20-foot intervals along the casing to the surface.

Methods for filter pack emplacement normally used for monitoring wells include: 1) gravity (free-fall); and 2) tremie pipe. Gravity emplacement is only possible in relatively shallow wells (less than ~50 feet) with an annular space of more than 2 inches where the potential occurrence of bridging is minimized. Bridging can result in the occurrence of large unfilled voids in the filter pack or the failure of filter pack materials to reach their intended depth. Gravity emplacement may also cause filter pack gradation. Additionally, formation materials from the borehole wall can become incorporated into the filter pack, potentially contaminating it.

With the tremie emplacement method, the filter pack is poured or slurried into the annular space adjacent to the well screen through a rigid pipe, usually 1.5 inches in diameter. Initially the pipe is positioned so that its end is at the bottom of the annulus. If the filter pack is being installed in a temporarily cased borehole (e.g., dual-tube percussion) the temporary casing is pulled to expose the screen as the filter-pack material builds up around the well screen. In unconsolidated formations the temporary casing should only be pulled out 1 to 2 feet at a time to prevent caving. In consolidated or well-cemented formations or in cohesive unconsolidated formations, the temporary casing may be raised well above the bottom of the borehole prior to filter pack emplacement. For deep wells and/or nonuniform filter pack materials, the filter pack may be pressure fed through a tremie pipe with a pump. Emplacement will be continuously monitored with a weighted measuring tape accurate to the nearest 0.1 foot to determine when the filter pack has reached the desired height.

4.3.5 ANNULAR SEAL

Proper annular seal formulation and placement results in the complete filling of the annular space and envelopes the entire length of the well casing to ensure that no vertical migration can occur within the borehole.

Annular seal materials will include bentonite chips or a high solids (approximately 10%) bentonite grout with a weight in the range of eleven to thirteen pounds per gallon of sealant. The grout will be mixed using the manufacturer's directions. A bentonite seal at least 2 feet thick will be emplaced immediately above the filter pack using a side-discharge tremie pipe. The use of bentonite as a sealing material depends on its efficient hydration following emplacement. Expansion of bentonite in water can be on the order of 8 to 10 times the volume of dry bentonite. This expansion causes the bentonite to provide a tight seal between the casing and the adjacent formation. Bentonite pellets, granules, or chip will be used for this seal. Bentonite pellets expand in water at relatively slow rates, thus reducing the potential for bridging compared to chips, chunks, or granules. If the bentonite seal will be above the saturated zone, several gallons of clean distilled water will be poured down the annulus to begin the hydration process. A minimum of 30 minutes should pass to allow for hydration before additional annular seal materials are placed above the bentonite.

The high solids grout will be mechanically blended in an aboveground rigid container and pumped through a tremie pipe to within a few inches of the bottom of the space to be sealed. This allows the grout to displace groundwater and loose formation materials up the hole. The end of the tremie pipe should always remain in the grout without allowing air spaces. After emplacement, the tremie pipe should be removed immediately. The grout should be emplaced in one continuous mass before initial setting of the cement or before the mixture loses its fluidity.

Cement is a highly alkaline substance (pH from 10 to 12) and introduces the possibility of altering the chemistry of the water it contacts. Thinner slurries may infiltrate an unprotected filter pack. After a borehole annulus is filled with grout a sample of water may be obtained and the pH determined in the field. A pH reading of 12 or higher may indicate an invasion of cement grout into the well.

4.3.6 SURFACE COMPLETIONS

Two types of surface completions will be used: aboveground and flush-mounted. Aboveground completions will be used wherever practical. Flush mounted completions will be used anywhere there may be vehicle traffic or where low visibility is preferred. The primary purpose of either type of completion is to prevent surface runoff from entering and infiltrating down the annulus of the well and to protect the well from accidental damage or vandalism. The surface seal may be an extension of the annular seal installed above the filter pack, or a separate seal emplaced atop the annular seal.

For aboveground completions, a protective steel casing fitted with a locking cover will be set into the uncured cement surface seal. Four guard posts (bollards) will be spaced around each well with above ground completions to afford additional protection.

In a flush-mount surface completion, a water-tight monitoring well Christy box or its equivalent will be set into the cement surface seal before it has cured. This type of completion is used in high-traffic areas. A low, gently sloping mound of cement will discourage surface runoff. A locking well cap will be used to secure the inner well casing.

4.3.7 SUMMARY OF WELL DESIGN

In summary, the filter pack and well design criteria for the investigations are listed below.

- PVC screen and casing
- Schedule 40 casing for wells less than 150 feet deep
- Schedule 80 casing for wells greater than 150 feet deep
- 0.020-inch machine slotted screen (If excessive fines are encountered in formational material, the field geologist may choose to install 0.010-inch slotted screen)
- 4-inch diameter casing
- Threaded flush joint casing and end-caps
- Centralizers in uncased holes
- #3 Monterey sand or equivalent for filter packs up to 3 to 5 feet above the top of the screened interval
- Bentonite plug at least 2 feet thick on top of filter pack
- Annular seal to the surface to consist of neat cement
- Both filter pack and annular seal are to be emplaced using a tremie pipe
- Surface completions will be aboveground stand-pipes with bollards unless in a vehicle traffic right-of-way of area where low visibility is preferred

5.0 PIEZOMETER INSTALLATION

Piezometers are typically installed at investigation sites where permanent groundwater monitoring wells are not required or are not feasible. Piezometers are primarily used for groundwater elevation studies. Piezometers differ from permanent monitoring wells mainly in construction and development standards. However, like permanent monitoring wells, piezometers will be designed to suit the hydrogeologic setting, the types of contaminants to be monitored, the overall purpose of the monitoring program, and other site-specific variables. Clear documentation of design parameters, construction details, and materials used will be maintained. During installation of piezometers, care will be taken to ensure that they do not serve as conduits for surface contaminants to the subsurface. Therefore, surface completions will follow essentially the same standards as outlined for monitoring wells.

5.1 BASIC INSTALLATION AND OPERATION OF PIEZOMETERS

A piezometer is essentially a device used for the measurement of hydraulic head. A piezometer must be sealed along its length, must be open to groundwater flow at the bottom, and be open to the atmosphere at the top. The intake is usually a section of slotted pipe or a commercially available well point. In either case, the intake is designed to allow the inflow of water but not of the sand grains or clay particles that make up the formation. A simple standpipe piezometer may be replaced in some applications by more complex designs utilizing pressure transducers, pneumatic devices, and electronic components.

Piezometers are installed using either direct-push methods or installed through a soil boring. With the use of direct-push methods, the piezometer pipe is attached to the push rods and driven to depth using a hydraulic ram. With use of a drill rig, the pipe is attached to standard soil sampling drill rods and driven to depth using either a standard 140-pound hammer, or hydraulically advanced into the water-bearing zone. Blow counts during advancement of the sampler should not exceed 30 per 6 inches. Piezometers can also be constructed in auger strings within a boring.

Unless otherwise specified in project-specific work plans, piezometers will be completed as naturally developed wells with the formation materials allowed to collapse around the screen. As previously described for monitoring wells, screen slot sizes will be based on grain-size distribution. Surface completions will be constructed in a similar manner as for monitoring wells. However, the protective outer PVC casing will not be installed. The piezometer will instead be fitted with a PVC end cap.

Piezometers will be constructed using one of three common methods:

1. Using the pull-back method
2. Driving the well point beyond the end of the casing into the formation below
3. Construction within drill pipes or augers

Pull-Back Method: In the pull-back method for piezometer installation, the casing is first set to the desired depth. A packer is then threaded to the top of the well point or riser pipe and lowered through the casing. After the well point has been lowered through the casing, the casing is pulled back to expose the screen to the water-bearing sediment. Drill tools (drill stem or driving bar) may be placed on the well point to hold it down as the casing is pulled back. Alternatively, some well points are manufactured with a drive plate mounted just above the point. The driving force is directed at the point, and the screen is pulled into place. However, care should be taken when using this technique as inside driving may cause severe damage to the bottom of the screen. All points to be driven from the inside should be identified as such when ordered from the manufacturer. Two-inch well points can be set in 4-inch diameter wells using the pull-back method.

Driven Well Point: Occasionally the pull-back method cannot be used because the friction on the pipe is so great that the force required to move the pipe might break it. In this case, a well point can be driven beyond the end of the casing into the sand formation below. All the sediment in the casing is removed to prevent the well point from becoming sand-locked inside the pipe. If the sediment tends to heave, the casing is kept full of water while the screen is set (any water used should be from an approved source and complete records of quantities used should be maintained). A self-sealing packer is attached to the well point, and the well point is dropped through the casing. A driving bar, drill stem, or other similar tool is lowered to the top of the packer and alternately raised and dropped to drive the well point out the bottom of the casing. Careful measurements must be made so the driller knows when the screen has been driven to the correct depth. A riser pipe may be used for this purpose.

Construction within Drill Pipe or Auger: Two-inch well points can be easily set through drill pipes or hollow stem augers once the pipes/auger-flight assembly has reached the desired depth. The screen is attached directly to the casing, and the string is lowered inside the pipes/augers to the bottom of the borehole. The pipes/auger flights are then pulled back to expose the screen and casing. This method is particularly suitable in shallow, caving formations.

6.0 WELL DEVELOPMENT

The goal of monitoring well development is to remove fines and drilling fluid residue from the gravel pack and the natural formation in the vicinity of the screened interval, this will assure good communication between the aquifer and the well. The result of well development is assurance that a sample collected will be a true representative of the quality of water moving through the formation.

The well development process is composed of: (1) the application of sufficient energy in a monitoring well to create groundwater flow reversals (surging) in and out of the well and the gravel pack to release and draw fines into the well; and (2) pumping or bailing to draw drilling fluids out of the borehole and adjacent natural formation along with fines that have been surged into the well.

6.1 GENERAL

The following general guidelines are applicable to well development regardless of method.

6.1.1 DECONTAMINATION

It is essential that every effort be made to avoid outside contamination and the cross-contamination of monitoring wells. This can accomplished by ensuring that all equipment is clean prior to being introduced into a well. Before use and between each site, all equipment and other non-sampling equipment will be decontaminated with high-pressure steam or scrubbed with a non-phosphate detergent and rinsed with water from an approved water source. If appropriate, equipment will be covered in plastic to protect it from the elements.

6.1.2 DOCUMENTATION

A critical part of monitoring well development is recording of significant details and events; a *Well Development Record* is provided in Attachment J. Listed are some important details to document.

- Well identification number
- Installation date
- Date and time of development
- Quantity of drilling fluid lost during well installation
- Measured well depth (pre-development and post-development)
- Water level
- Height of water column
- Pumping rate and water level draw down (if applicable)
- Recharge rate (poor, good, excellent)
- Periodic parameter readings
- Sample observations
- Type of equipment used
- Total amount of water removed
- Completion time

6.1.3 WELL PURGING

The total volume of water purged during the development process will be based on two factors: (1) indicator parameters and (2) minimum purge volume.

6.1.3.1 Indicator Parameters

During the development process, the indicator parameters pH, temperature, electrical conductivity and turbidity will be measured. The parameters pH, temperature and electrical conductivity will be measured with a field meter while turbidity will be described qualitatively. Other observations of the water, such as color and odor, will also be recorded. Measurement of the indicator parameters will be taken at the beginning and end of the development process and at least once every ½-casing-volume with a minimum of 4 measurements. Once the minimum required volume is reached, as described in Section 6.1.3.2, purging will continue until three consecutive measurements of the stabilization parameters meet the stabilization requirements shown below.

pH	± 0.2 units	
Conductivity	± 3% of span	(i.e., ± 0.03 for span of 0 to 1 mS/cm)
Temperature	± 1^{o}C	
Turbidity	± 10%	

However, if the indicator parameters have stabilized, but there are still significant changes in color or some other qualitative characteristic, purging will continue until it has stabilized, if practical.

6.1.3.2 Purge Volume

Before the development process begins, the minimum number of gallons to be removed will be calculated. The minimum number of gallons to purge will be equal to three casing volumes or one purge volume (described below), whichever is larger.

Information needed to calculate purge volume is listed below.

1. Total depth of well (TD)
2. Measured static water level (WL)
3. Screen length (SL)
4. Well casing inner diameter (ID)
5. Borehole Diameter (BD)
6. Number of gallons of water used during well drilling/construction
7. If the standing water column (SC) is longer then the screen length, you will need to note how many feet of filter pack was installed above the screen.

Calculating one well volume:

- To calculate standing water column (SC), TD - WL = SC
- Use a well volume chart to find a multiplier in the "gallons per foot" column that coincides with the wells ID. This volume chart is located in Attachment J.
- SC x ID multiplier = gallons of water in one well volume

Calculating one annulus volume (2 Options):

Option 1, if SC is shorter then the screen length

- Portion of saturated annulus = SC
- Use a volume chart to find a multiplier in the "Gallons per foot" column that coincides with the wells BD
- BD multiplier - ID multiplier = annulus multiplier
- Feet of saturated annulus x annulus multiplier x 30% (assumed porosity) = gallons of water in one annulus volume

Option 2, if SC is longer then the screen length

- Portion of saturated annulus is = to the screen length + the number of feet of sand above the top of the screen
- Use a volume chart to find a multiplier in the "Gallons per foot" column that coincides with the wells BD
- BD multiplier - ID multiplier = annulus multiplier
- Feet of saturated annulus x annulus multiplier x 30% (assumed porosity) = gallons of water in one annulus volume

Calculating the minimum gallons to be removed: well volume + annulus volume + number of gallons lost during well drilling/construction = one purge volume

Example:

You are to develop a 4-inch well. From the Well Construction Diagram you note the borehole diameter was 11 inches, the screen is 15 feet long and the driller used 75 gallons of water during well construction. With a water level indicator you measure the static water level at 59.45 feet and with a well tagger you measure the well depth at 71.21 feet.

Record in log book: TD = 71.25'
WL = 59.45'

TD -WL = SC
Log book: SC = 11.8'

From a Volume chart, the "gallons per foot" multiplier for a 4-inch well is 0.653 and 11.8 x 0.653 = 7.71 (gallons of water in one well volume).

Log book, One well vol. = 7.71 gallons

From a Volume chart, the "gallons per foot" for an 11-inch borehole is 4.937. Therefore, 4.937(BD multiplier) - 0.653(ID multiplier) = 4.284(annulus multiplier). And, 11.8 x 4.284 x 30% = 15.17 (gallons of water in one annulus volume).

Log book, One annulus vol. = 15.17 gallons
Drilling fluid lost = 75 gallons

7.71(one well volume) + 15.17(one annulus volume) + 75(fluid lost) = 97.88 gallons (one purge volume). A minimum of 3 well volumes must be removed during development. Additional water may need to be purged to allow the parameters to stabilize and the water to clear up.

Log book, One purge vol. = 97.88 gallons
97.88 x 3 = 293.64 (minimum number of gallons to be purged).
Log book, Min. gal. to be purged = 293.64 gallons

6.2 WELL DEVELOPMENT

Development will be accomplished using surge and bail/pump. In relatively clean and permeable formations where water flows freely into the borehole, bailing, surging and pumping is an effective development technique. First, the bottom of well will be tagged to measure the amount of sand/silt before and after surging that may be present at the bottom of the well. Then a bailer will be lowered down the well to clean out any fines that have settled on the bottom of the well. Then a surge block, slightly smaller than the inside diameter of the well casing, will be used to agitate the water, causing it to move in and out of the screen, thus drawing in fines from the gravel pack and surrounding formation and breaking up any bridges that may have occurred during the placement of the gravel pack. After surging for a few minutes (depending on the height of the water column and length of screen), the bailer will then be lowered again to clean out any fines that were drawn into the casing as a result of surging. This surge/bail technique will continue until minimal fines are being pulled out with the bailer. A submersible pump will then be lowered down the well. Pumping will begin at the top of the saturated portion of the screened interval to prevent sand locking of the pump. The pump will be lowered at intervals of 5 feet or less until the pump is resting approximately 1 foot off the bottom of the casing. The water level will be monitored continuously during the first few minutes of pumping so as not to draw the water level below the pump intake and break the suction. The discharge flow rate will be increased (if possible) until the well is pumping at its maximum yield without draw down beneath the pump.

Developing low-yield wells is a very lengthy process. If development exceeds five hours, the remaining development will be done in stages (demobilize and remobilize), not to exceed three casing volumes or two return trips to the well. For wells installed in clay or fine-grained silt, the method of development will be bailing only. Surging of such wells has been found to substantially increase the turbidity of the water and does not significantly improve hydraulic well response. These wells will be bailed dry and a record kept on the time it takes for the well to recharge 80 percent.

A *Well Development Record* is provided in Attachment J.

7.0 AQUIFER TESTING

Determining the hydraulic properties of an aquifer is a fundamental component of the site characterization process. This section details aquifer test methods that are commonly implemented to help characterize an aquifer, and evaluate the performance characteristics of a monitoring well.

Aquifer parameters can be determined by employing either ex-situ or in-situ methods. Ex-situ methods involve collecting samples of the aquifer material and testing them in a geotechnical lab. In-situ methods involve determining the hydraulic characteristics of the aquifer by applying a stress to the aquifer and recording the response to that stress over time. In-situ methods are generally considered more representative of aquifer conditions than ex-situ (laboratory) soil permeability testing. As a result, this SOP only describes in-situ aquifer testing. Data resulting from these tests can be used in standard well flow equations to determine the hydraulic parameters of the aquifer and the monitoring/extraction well in which the tests are performed.

Each aquifer test method has certain applications, effort requirements, costs, risks, and limitations, and will be evaluated based on the project goals, design requirements, long-term planning, budget, schedule, and regulatory concerns. In addition, aquifer testing may be conducted in several phases involving one or more of the above methods. This iterative approach may be very effective in that the aquifer-testing program can be tailored to meet the project needs as the site characterization or basin study evolves.

Aquifer tests are typically conducted during the site investigation, although they may also be performed at any phase of an investigation. A great deal of care will be given to data collection methods and data analysis for aquifer tests, as the findings will subsequently be used for long-term resource planning, engineering design, and capitol expenditures. The findings from an aquifer testing program can ultimately be used for several important purposes, including the following:

- Development of the site conceptual hydrogeologic model. Aquifer testing provides the mechanism to quantify and incorporate soil heterogeneity and hydraulic anisotropy into the conceptual model

- Development of analytical groundwater flow solutions (models) such as determination of a groundwater flow velocity

- Evaluation of contaminant fate and transport mechanisms associated with advection

- Generation of parametric data for numerical groundwater flow models and associated solute transport models

- Development of groundwater extraction scenarios for hydraulic containment, collection of contaminants, and aquifer restoration

- Wellhead protection studies (determination of the zone of influence and zone of contribution for production wells) and other groundwater basin studies.

7.1 DEFINITIONS

Various physical properties and hydraulic parameters of aquifers and aquitards are important in describing groundwater flow, and are therefore significant in aquifer testing studies. A thorough understanding of the hydraulic principles involved in aquifer testing is an essential component of aquifer analysis. A brief definition of terms that are used in this section are provided below:

Bailing Line: A line used for rapidly lowering and raising the slug into the water column. Deep wells may require the use of the winch on a drill rig.

Darcy's Law: States that the rate of flow through a porous medium is proportional to the loss of head, and inversely proportional to the length of the flow path, or

(eq. 1) $$v = K(dh/dl)$$

Where:

- v = Q/A, which is the specific discharge, also known as the Darcy velocity or Darcy flux, (length/time),
- Q = the volume rate of flow ($length^3$/time),
- A = the cross sectional area normal to flow direction ($length^2$),
- dh/dl = describes the aquifer hydraulic gradient (length/length) and,
- K = describes the hydraulic conductivity of the aquifer.

Equation 1 may be rewritten as:

(eq. 2) $$Q = K(dh/dl)A$$

It should be noted that the specific discharge is in velocity units of length/time. It is important to also note that this is a macroscopic concept, and must be differentiated from microscopic (real) flow velocities, which consider the porosity of the medium, as:

(eq. 3) $$v = \frac{K(dh/dl)}{n}$$

where "n" is the effective porosity of the media.

Data Logger: A small field computer capable of recording a wide range of physical measurements such as pressures, temperatures, electrical conductivities, and flow. For aquifer analysis, pressure is generally the parameter of interest (feet of water in the well). The data logger converts the pressure value sent by the transducer into feet of water above the transducer, and records the values in its memory. The data can then be transferred from the logger to a personal computer via a standard RS-232 port.

Each transducer has specific parameters that must be input to the data logger to make the appropriate conversions from pressure units to feet. It is extremely important that field personnel operating a data logger be properly trained on the use of the instrumentation to ensure proper collection of test data.

Common data logger models are the Hermit 3000 (8-channels plus an internal barometer, very user friendly) and Hermit 2000 (8-channels, less user friendly). The Hermit 3000 data logger also contains a RS-422 communication port.

Drawdown: The amount of water level decline in a well and aquifer due to pumping. Usually measured and reported in terms of feet of drawdown relative to static (non-pumping) conditions (‘s’ by convention).

Electric Submersible Pump: A pumping device capable of pumping for extended periods of time at a constant discharge rate. Discharge pipe or hose should be fitted with a valve to provide the ability to adjust flow. Adjusting the discharge rate by adjusting the speed of the pump is less desirable than the use of a valve. An exception is the variable-speed 2-inch-OD Grundfos submersible pumps, which are designed for adjustable speed (flow) settings. A shroud is recommended if a 2-inch pump is used in a 4-inch or greater diameter well to ensure long-term cooling of the pump motor. The pump will require a reliable power source.

Flow Gauge: An in-line, "turbine type" flow meter is recommended for most moderate to high flow-rate applications. Other means of gauging flow include the use of calibrated orifice weirs or an orifice bucket. For low flow applications, a container and stopwatch method may be suitable. The container method requires measuring the time it takes to fill a container of known volume, such as a 5-gallon bucket or 55-gallon drum. The flow gauging method should be accurate to +/- 5 percent.

Hydraulic Conductivity: This property is a constant of proportionality that describes fluid flow through a porous media (see Darcy's Law, above). Hydraulic conductivity ("K" by convention) is a function of the permeability of the media and of the physical properties of the fluid. Hydraulic conductivity has the units of length/time. In a normal groundwater setting, where the physical properties of the water are considered relatively constant, hydraulic conductivity can be considered a function of the porous media.

For this reason, the terms permeability and hydraulic conductivity are often used interchangeably for groundwater settings. Because hydraulic conductivity varies over 13 orders of magnitude for earth materials (Freeze and Cherry, 1979), order-of-magnitude approximations are generally considered appropriate for evaluation of aquifer properties.

Potentiometric Surface: An imaginary surface connecting points to which water would rise in cased wells from a given point in an aquifer (Lohman, 1979). It may be above or below the ground surface. The water table is a particular potentiometric surface for unconfined aquifers. "Potentiometric" is preferable to the term "piezometric" used by many in the past.

Pressure Transducer: A device installed in the well below the water surface that is capable of continuously providing very accurate water level measurements. The transducer is connected to a continuous data logger (described above). Transducers are available in different pressure (and accuracy) ranges. The transducers should never be lowered into a water column below the operating pressure range of the transducer. Higher pressure range transducers are less accurate than lower pressure range transducers. As a rule, a multiplier of 2.3 can be used to estimate the maximum total amount of water above a transducer (i.e., a 10-psi transducer can have 23 feet of water above, a 50-psi transducer can have 106 feet of water above, etc.). For example, if a 10-psi transducer is installed at the bottom of the well with 100 feet of water above it, it will no longer function properly, and must be returned to the manufacturer for recalibration.
Please note, the transducer only needs to record the change in water levels, and therefore should be installed immediately below the lowest depth expected. A 10-psi transducer is capable of measuring up to 23 feet of change in water levels to 0.01 foot accuracy, and is therefore the recommended transducer for slug tests. Transducers will operate improperly if lowered into sediment, and therefore should never be lowered to the bottom of the well. The target depth of the transducer should be identified prior to lowering into the well, and then the transducer cable should be marked with duct tape to ensure that the transducer is not lowered too deep.

Residual Drawdown: Once a pump is shut off during a pumping test, water levels in pumping wells, observation wells, or piezometers will rise. This rise in total head results from the principle of superposition, and is commonly known as residual drawdown (‘s’ by convention). It is expressed as the difference between the static water level and the water level at time t' after the cessation of pumping.

Slug: A solid pipe used to displace water by insertion or withdrawal from a well. Bailers may also be used for slug withdrawal only. The slug volume should be maximized based on field conditions. Different length slugs, capable of threading together, should be brought to the field to provide flexibility to the program. A typical slug used for a 2-inch-diameter monitoring well may be 1.5 inches in diameter and 6 to 10 feet in length. The volume of the slug used for each test must be recorded in the field notes.

Specific Capacity: The specific capacity is defined as the discharge rate per unit length of drawdown for a pumping well. Typically expressed in gallons per minute per foot of drawdown (gpm/ft).

Specific Yield: The specific yield is the volume of water released by gravity drainage from an unconfined aquifer from storage per unit surface area of the aquifer per unit decline in the watertable. Specific yield is also known as unconfined storativity, effective porosity, or drainable pore space. Specific yield is unitless and typically ranges from 0.01 to 0.3 (Kruseman and de Ridder, 1991).

Static Water Level: The non-pumping, stabilized water level in a cased well or piezometer. Usually recorded in the field as depth to water below a datum such as the top of casing. This term is usually reported in feet above mean sea level.

Storativity: The storativity of a confined aquifer is the volume of water released from storage per unit surface area per unit change in head. For confined aquifers, stored water is released via aquifer compression and expansion of water. In an unconfined (watertable) aquifer, the storativity is equivalent to the specific yield and is also known as the storage coefficient. Storativity is dimensionless and typically ranges from $5x10^{-5}$ to $5x10^{-3}$ (Kruseman and de Ridder, 1991).

Total Head: The sum of the elevation head, the pressure head, and the velocity head at any given point in an aquifer.

Transmissivity: The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient (Fetter, 1980). This term ("T" by convention) is simply the product of the hydraulic conductivity (K) and the aquifer thickness ("b" by convention).

$$T = Kb \quad \text{(eq. 4)}$$

Transmissivity may vary significantly due to spatial variations in both the thickness and conductivity of the aquifer. Transmissivity carries the units $length^2/time$. For aquifers, b is the thickness of the confined aquifer. For unconfined aquifers, b is the thickness of the saturated portion of the aquifer.

Water Level Indicator: A device used to measure static water levels. An electrical conductivity-based water level indicator capable of measuring to 0.01 foot accuracy is required for all measurements.

7.2 AQUIFER TESTING METHODS

All aquifer test methods, such as slug tests, pumping tests, and recovery tests, have unique advantages and limitations. This section describes the principles, methodology, and staffing requirements for slug testing and pneumatic slug testing. Several methods are described here, paying attention to the limitations of each.

7.2.1 SLUG TESTING

Principle: Slug testing involves either introducing or removing a "slug" of known volume into or from a well and recording the water level changes that result. The rate of recovery observed in the well is a function of the hydraulic properties of the aquifer and of the well itself. The transmissivity of the aquifer can then be estimated using appropriate well-flow equations.

Assumptions and Limitations of Slug Testing: Slug tests stress only a small portion of the aquifer adjacent to the well, and therefore, slug tests are incapable of evaluating hydrogeologic boundary conditions, hydraulic anisotropy, storage coefficients, and pumping characteristics of the well. However, slug tests commonly provide a cost-effective means of gathering "point" transmissivities across a screen interval. Slug tests are commonly considered as a first step in characterizing an aquifer because of the relative low cost and effort requirements. Additionally, slug tests do not generate large volumes of groundwater, and therefore often used to initially characterize water-bearing zones beneath hazardous waste sites, where disposal options of contaminated groundwater may be limited or costly.

It is important to note that slug tests do not provide adequate information regarding the hydraulic characteristics of a pumping well. Additionally, because of the small stress applied to the aquifer, data may be influenced by drilling methods (skin effects), well construction, and development procedures. Slug tests alone cannot provide accurate information regarding boundary conditions, anisotropy, or storage coefficient data, and are therefore not useful for predicting steady-state drawdowns resulting from any given hypothetical pumping scenario. The development of long-term groundwater extraction scenarios, such as in most modeling studies, should therefore not be based solely on slug test data, but require more sophisticated pumping tests, if feasible.

Falling Head Slug Tests: Falling head slug testing involves the insertion of a slug into the well that is screened below the water table. If a slug is rapidly inserted into the water column in a well, it will instantaneously raise the water column in the well. The amount of head change is defined as the instantaneous head (H_O). The water column will then "fall" to the static water level at a rate that is controlled by the hydraulic characteristics of the water-bearing formation and of the well itself. Falling head slug tests are not appropriate for water table wells (i.e., wells in which part of the screen is unsaturated and the screened interval is within the first water encountered).

Rising Head Slug Tests: Rising head slug testing requires submerging the slug under water in a well, and allowing the water level to stabilize to static conditions. The slug is then rapidly withdrawn from the well. After the slug is withdrawn from the well, the instantaneous water level will be at a level that is lower than the static water level. The rate at which the water level recovers to static condition is a function of the aquifer properties and of the well itself.

Both falling and rising head methods can be used in series during a slug testing program. The slug insertion method may be followed by the slug withdrawal with relative ease. However, if a slug insertion method is chosen for unconfined aquifers, groundwater will be displaced above the water table and into the unsaturated sand filter pack of the well and the formation itself. It should be noted that the hydraulic conductivity of the soils overlying the water-bearing zone may differ from those of the aquifer. Additionally, hydraulic conductivity of unsaturated soils varies as a function of moisture content. For these reasons, a slug withdrawal method is generally considered advantageous to slug insertion in unconfined or semiconfined aquifers due to two-phase (air and water) flow. A good rule-of-thumb is that if the static water level is within the screened interval of the well being tested, a slug withdrawal method should be chosen for aquifer analysis.

Selection of the Slug: Several different types of slugs may be used for the test, including:

- Solid pipe fitted with an eye bolt at one end to affix a bailing line

- Stainless steel or Teflon bailers
- A slug of water of known volume.

Introduction of a slug of water (usually distilled, organic-free water) may not be feasible due to regulatory restrictions. In addition, it is generally considered infeasible to "instantaneously" withdraw a slug of water using a pump. The withdrawal of a slug of water is limited to the use of bailers. The most common slug test involves the use of solid pipes (either slug insertion or withdrawal methods), or the use of bailers (slug withdrawal only).

An additional slug testing method involves applying a pressure or vacuum to the well head and measuring changes in water levels that result following the removal of the pressure. This method requires specialized well fittings, generators, and compressors. Details of this method are provided in Kruseman and de Ridder (1991) (Oscillation Method, p.238), and are not included in this SOP.

The remainder of this section focuses on slug tests conducted using a solid slug, although the general methods for slug tests analyses do not vary significantly if other types of slugs are used for the test.
A large slug will stress the aquifer to a greater degree than a small slug, and therefore the size of the slug should be maximized based on field conditions. Three-foot Teflon bailers or sections of solid pipe can be threaded together to optimize slug volume. The size of the slug is limited only by the standing water column in the well and physical limitations in one's ability to instantaneously insert or withdraw the slug.

Slug Insertion (Falling Head) Test Methods: The procedures outlined below will be followed while conducting falling head slug tests.

1. Remove the well head expansion cap and allow the well to equilibrate to atmospheric conditions.

2. Record the static water level using a conductivity-based water level indicator. Measure the total depth of the well. Note: potential sediment at the bottom may have decreased the total depth value recorded during construction.
3. Determine the appropriate depth of 10-psi transducer. This will generally be between 10 and 20 feet below the static water level, or above potential sediment at the bottom of shallow wells. Affix duct tape to transducer cable to indicate the target depth below top of casing.

4. Lower a 10-psi transducer to the target depth. The transducer and transducer cable must hang plumb in the well to minimize entanglement with the slug. Duct-tape the transducer cable to an immovable object, such as the top of casing. Allow the well to equilibrate to static water levels.

5. Connect the pressure transducer to a continuous data recorder. Input the required transducer parameters and other test parameters in the data logger. The data logger will need to be referenced to the top of casing (TOC) or surface (static water level datum). It is recommended that it is "zeroed" to the static water level, and therefore measured water level changes will be relative to static water level. Water levels above static water levels will be recorded as positive, and water levels below static will be recorded as negative values. The slug test requires only measuring the change in head associated with slug insertion or withdrawal. The "surface mode" is therefore the desired data logger "mode" for slug testing**.** “TOC mode” refers to measuring the absolute value (i.e., total head) of the water level relative to the TOC datum. This is an unnecessary step that may introduce error in the field, and is therefore not

recommended for slug testing. An accurate record of all input parameters and field observations will be included in the field logbook.

6. "Zero" the pressure transducer/data logger to static water levels. Confirm static levels with a water level indicator. The data logger should be set to begin the test in the "immediate" mode (i.e., no time delay). The data logger will be set to record water levels as frequently as possible (i.e., using the "log" mode and default settings).

7. Affix a bailing line to the slug. To accurately complete the test, the slug will be completely submerged in the well. Record the volume of the slug in the field log. Determine the total depth required to submerse the slug. A piece of duct tape may be used to identify the desired length of the bailing line. The slug will be lowered to a "ready" position immediately above the static water level. The slug must not be tangled with the transducer cable.

8. ***Critical step.*** On a pre-determined count, ***lower*** the slug rapidly (but gently) to total submersion and trigger the data logger to begin recording water levels. The slug should remain motionless once it has been lowered into the well. The bailing line for the slug will be tied to an immovable object (tailgate of truck, etc.) once the slug is submerged. Allow the data logger to complete it's logarithmic data recording cycle (approximately 2-3 minutes) prior to confirming water levels with a water level indicator. Wells screened within low to moderately transmissive aquifers may require from 30 seconds to several minutes or even hours to recover to static water levels. If the well recovers within a few seconds, it is likely that the well is screened within a moderate to high transmissivity zone, and therefore the slug test method is likely not an appropriate test method for the determination of aquifer properties.

9. The slug injection test is completed when the water level recovers to static water levels. In many instances, the final few tenths of a foot of recovery may require a significant amount of time (hours). The field team will use their best judgement regarding when to terminate the test. It should be noted that for nearly all methods of data analysis, the last data points are equally significant as the initial data points. The validity of the tests will not be compromised due to impatience of field team members. In many cases, the team can be setting up the next test on a different well while the previous well completes its recovery.

10. Once the well has equilibrated to at least 90 to 95 percent of static water level, the test can be terminated by stopping the data logger. However, at this time, it would be advantageous to initiate a slug withdrawal test (see item #6 below). This may be accomplished by either "stopping" the insertion test, or "stepping" the test by using the "Step" function of the data logger. The original input parameters remain unchanged if you choose to use the "Step" function or stop and start function. Both methods involve restarting the "log cycle" for the data logger (highly desirable for the early time data). An accurate record of test numbers and step numbers will be maintained in the field logbook.

Slug Withdrawal (Rising Head) Test Methods: Follow steps 1 through 5 as described above for the falling head slug test. Steps 6 through 8, below, describe the slug withdrawal test method.

6. Lower the slug into the water column so the slug is fully submerged. For this test, tie the slug bailing line to an immovable object and allow the slug to remain motionless in the well. Ensure that the slug is not entangled with the transducer or transducer cable.

7. Allow the well to equilibrate to the static water level. The well recovers most quickly if a bailer is used for the slug. A solid pipe slug requires a longer period of time to recover. Verify that the well has equilibrated to static water level with a water level indicator.

8. ***Critical step.*** On a pre-determined count, one person will rapidly (and in a fluid motion) ***retrieve*** the slug from the well while the second person simultaneously triggers the data logger to begin recording water levels. Remove the slug from the well while making sure not to disturb the transducer cable. As stated above, allow the data logger to complete it's logarithmic data recording cycle (approximately 2-3 minutes) prior to confirming water levels with a water level indicator. Wells screened within low to moderately transmissive aquifers may require from 30 seconds to several minutes or hours to recover to static water levels. If the well recovers within a few seconds, it is likely that the well is screened within a moderate to high transmissivity zone, and therefore the slug test method is likely not an appropriate test method for determination of aquifer properties.

Slug Withdrawal (Pneumatic) Test Methods:

1. Measure the static water level.
2. Determine the distance from static water level to the top of the screen. (The amount of downward pressure imparted by the air must not exceed this distance.).
3. Install the pneumatic slug testing well assembly. This includes;
   a. A quick-release ball valve at the top of the unit is the same diameter as the well or larger
   b. A manual air gauge that monitors the pressure injected into the well head and is preferably graduated in inches or centimeters of water for use
   c. An air injection port that can accommodate standard air tools
   d. A base that can accommodate either two-inch or four-inch wells and has an easy-to-install airtight seal
4. Orient the ball valve such that upon opening the valve, air will flow straight through the entire unit without turning any corners.
5. Insert the probe port so that it will not interfere with the ball valve and allows for effective air sealing around the transducer cable
6. Program the transducer to desired settings
7. Pressurize the well to a pressure equivalent that is four to eight feet of water, but do not exceed the previously determined maximum.
8. Wait for the pressure gauge on the well head to stabilize; when the aquifer is approaching equilibration and the test may commence.
9. Start the test on the instrument, wait for a few seconds, and then open the ball valve at the well head and allow the air to escape from the well.
10. Monitor the water level as it rises. The test is complete when the water level has risen to the approximate original static water level.
11. Once equilibrium was reached, the data logger was started to collect a few static data points prior to opening the ball valve and releasing the slug. After the slug is released, the transducer will record the water-level recovery.
12. The final segment of the curve will be used to analyze the data and calculate the hydraulic conductivity of the aquifer

It is recommended that two slug tests be conducted for each well for data verification purposes. Most data loggers allow the user to view the data or download the data to a field personal computer. Data will be reviewed in the field following completion of the test to ensure that the transducers and data logger are functioning properly.

The initial head values (H_o) which result from instantaneous withdrawal or injection of the slug will be evaluated against the maximum theoretical drawdown. This can easily be completed by calculating the volume of the slug and converting volume of the slug to volume of water in a well. The well volume can then be converted to feet of water in the well column. An example calculation is provided below:

Hypothetical slug size:

0.75-inch outer diameter (OD) x 60-inch length = 106.05 in.^{3}

Conversion to gallons:

106.05 in.^{3} x (0.004329 gallons/in.^{3}) = 0.46 gallons

Conversion to feet (assumes a 2-inch inner diameter (ID) well):

0.46 gallons x (1 foot/0.16 gallons) = 2.88 feet

Therefore, using a slug that is 0.75 inches in diameter and 60 inches (5 feet) in length, the maximum anticipated change in water level with respect to static levels (H_o) would be 2.88 feet. This should be evaluated against the maximum head change observed in the field. Significantly different (greater than 20-30 percent) values may indicate that the transducers or data loggers are not functioning properly. Other possibilities are that the slug is not being inserted or withdrawn rapidly enough, or that the timing between the "trigger" operator and the "slug" operator is off. These factors will be evaluated and resolved prior to conducting additional slug tests.

Data loggers generally have sufficient memory to record an entire day of slug testing. The data will be downloaded daily to minimize the risk of loss of data. An electronic and hard copy will be stored.

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ATTACHMENTS

ATTACHMENT A

GLOSSARY OF TERMS

Absorption - The penetration or apparent disappearance of molecules or ions of one or more substances into the interior of a solid or liquid.

Adsorption - The process by which atoms, ions, or molecules are held to the surface of a material through ion-exchange processes.

Angular - Particles have sharp edges and relatively planar sides with unpolished surfaces

Annular Sealant - Material used to provide a positive seal between the borehole and the casing of the well. Annular sealants should be impermeable and resistant to chemical or physical deterioration.

Annular Space - The space between the borehole wall and the well casing, or the space between a casing pipe and a liner pipe.

Annulus - The gap between the well and borehole where the sand, seal and grout are installed.

Aquifer - A geologic formation, group of formations, or part of a formation that can yield water to a well or a spring.

Backwashing - A method of filter pack emplacement whereby the filter pack material is allowed to fall freely through the annulus while clean fresh water is simultaneously pumped down the casing.

Bailer - A cylindrical tool designed to remove material, both solid and liquid, from a well or borehole. A valve at the bottom of the bailer retains the material in the bailer. The three types of bailers are flat-valve bailer, a dart-valve bailer and the sand pump with rod plunger.

Bailing Line: A line used for rapidly lowering and raising the slug into the water column. Deep wells may require the use of the winch on a drill rig.

Bentonite - Hydrous aluminum silicate available in powder, granular, or pellet form. It is used to provide a tight seal between the well casing and the borehole.

Blow Counts - Number of hammer blows needed to advance a split spoon sampler. Blow counts are usually counted in 6-inch increments.

Boulders - Particles of rock that will not pass a 12-in. (300-mm) square opening.

Borehole - The hole created by drilling through the subsurface.

Bridge - A wedge or build up of sand that occurs when the driller is pouring the sand pack around the screened interval, thus leaving a gap or "open zone" where the natural formation could possibly clog the screen. Also the development of gaps or obstructions in either grout or filter pack materials during emplacement.

Clay - Soil passing a No. 200 (0.003 in. or 75-µm) sieve that can be made to exhibit plasticity within a range of water contents and that exhibits considerable strength when air-dried. Individual clay particles are not visible to the naked eye.

Cobbles - Particles of rock that will pass a 12-in. (300-mm) square opening and be retained on a 3-in. (75-mm) sieve.

Cone Penetrometer - An instrument used to identify the underground conditions by measuring the differences in the resistance and other physical parameters of the strata. The cone penetrometer consists of a conical point attached to a drive rod of smaller diameter. Penetration of the cone into the formation forces the soil aside, creating a complex shear failure. The cone penetrometer is very sensitive to small differences in soil consistency.

Continuous Slot Wire-Wound Intake - A well intake that is made by winding and welding triangular-shaped, cold-rolled wire around a cylindrical array of rods. The spacing of each successive turn of wire determines the slot size of the intake.

Core Barrel - A steel tube used to collect rock core samples. The core barrel receives the rock core cut by the outer barrel as the borehole is advanced.

Cuttings - Formation particles obtained from a borehole during the drilling process.

Data Logger: A small field computer capable of recording a wide range of physical measurements such as pressures, temperatures, electrical conductivities, and flow. For aquifer analysis, pressure is generally the parameter of interest (feet of water in the well). The data logger converts the pressure value sent by the transducer into feet of water above the transducer, and records the values in its memory. The data can then be transferred from the logger to a personal computer via a standard RS-232 port.

Darcy's Law: States that the rate of flow through a porous medium is proportional to the loss of head, and inversely proportional to the length of the flow path, or

(eq. 1) $v = K(dh/dl)$

Where:

v = Q/A, which is the specific discharge, also known as the Darcy velocity or Darcy flux, (length/time),
Q = the volume rate of flow (length^3/time),
A = the cross sectional area normal to flow direction (length^2),
dh/dl = describes the aquifer hydraulic gradient (length/length) and,
K = describes the hydraulic conductivity of the aquifer.

Equation 1 may be rewritten as:

(eq. 2) $Q = K(dh/dl)A$

It should be noted that the specific discharge is in velocity units of length/time. It is important to also note that this is a macroscopic concept, and must be differentiated from microscopic (real) flow velocities, which consider the porosity of the medium, as:

(eq. 3) $$v = \frac{K(dh/dl)}{n}$$

where "n" is the effective porosity of the media.

Dilatancy Reaction - The speed with which water appears in a moist pat of soil when shaking in the hand and disappears while squeezing.

Drawdown: The amount of water level decline in a well and aquifer due to pumping. Usually measured and reported in terms of feet of drawdown relative to static (non-pumping) conditions ('s' by convention).

Dry Strength - The ease with which a dry lump of soil crushes between the fingers.

Drill Rod - The rigid steel rod used to lower and retrieve cutting, coring and sampling equipment down the borehole.

Draw down - Distance between the static water level and water level while the well is being pumped or bailed at a constant rate.

Drilling Fluids_- A water-based or air-based fluid used in the well drilling operation to remove cuttings from the borehole, to clean and cool the bit, to reduce friction between the inner barrel and the sides of the borehole and to seal the borehole.

Dual-Purpose Well - A well that can be used as both a monitoring and extraction or injection well.

Elastic silt (MH) - the soil has low to medium dry strength, no to slow dilatancy and low to medium toughness and plasticity; will air dry more quickly than lean clay and have a smooth, silky feel when dry.

Electric Submersible Pump: A pumping device capable of pumping for extended periods of time at a constant discharge rate. Discharge pipe or hose should be fitted with a valve to provide the ability to adjust flow. Adjusting the discharge rate by adjusting the speed of the pump is less desirable than the use of a valve. An exception is the variable-speed 2-inch-OD Grundfos submersible pumps, which are designed for adjustable speed (flow) settings. A shroud is recommended if a 2-inch pump is used in a 4-inch or greater diameter well to ensure long-term cooling of the pump motor. The pump will require a reliable power source.

Falling Head Slug Tests: Falling head slug testing involves the insertion of a slug into the well that is screened below the water table. If a slug is rapidly inserted into the water column in a well, it will instantaneously raise the water column in the well. The amount of head change is defined as the instantaneous head (H_o). The water column will then "fall" to the static water level at a rate that is controlled by the hydraulic characteristics of the water-bearing formation and of the well itself. Falling head slug tests are not appropriate for water table wells

Fat clay (CH) - soil has high to very high dry strength, no dilatancy and high toughness and plasticity.

Flow Gauge: An in-line, "turbine type" flow meter is recommended for most moderate to high flow-rate applications. Other means of gauging flow include the use of calibrated orifice weirs or an orifice bucket. For low flow applications, a container and stopwatch method may be suitable. The container method requires measuring the time it takes to fill a container of known volume, such as a 5-gallon bucket or 55-gallon drum. The flow gauging method should be accurate to +/- 5 percent

Filter Pack - Sand, gravel, or glass beads that are uniform, clean and well-rounded that are placed in the annulus of the well between the borehole wall and the well intake to prevent formation material from entering through the well intake and to stabilize the adjacent formation.

Fines - Silt, clay, fine sand.

Gravel - Particles of rock that will pass a 3-in. (75-mm) sieve and be retained on a No. 4 (4.75-mm) sieve.

Grout - A fluid mixture of neat cement and water with various additives or bentonite of a consistency that can be forced through a pipe and emplaced in the annular space between the borehole and the casing to form an impermeable seal.

Heaving Formation - Unconsolidated saturated substrate encountered during drilling where the hydrostatic pressure of the formation is greater than the borehole pressure causing the sands to move up into the borehole.

Hydraulic Conductivity: This property is a constant of proportionality that describes fluid flow through a porous media (see Darcy's Law, above). Hydraulic conductivity ("K" by convention) is a function of the permeability of the media and of the physical properties of the fluid. Hydraulic conductivity has the units of length/time. In a normal groundwater setting, where the physical properties of the water are considered relatively constant, hydraulic conductivity can be considered a function of the porous media.

Inner Barrel - The tool lowered through the inside of the outer barrel that can be configured for cutting, coring, or sampling.

Kelly Bar - A hollow steel bar or pipe that is the main section of drill string to which the power is directly transmitted from the rotary table to rotate the drill pipe and bit. The cross section of the kelly is either square, hexagonal, or grooved. The kelly works up and down through drive bushings in the rotary table.

Lean clay (CL) - soil has medium to high dry strength, no or slow dilatancy and medium toughness and plasticity.

Neat Cement - A mixture of Portland cement and water in the proportion of 5 to 6 gallons of clean water per bag (94 pounds) of cement.

Organic soil (OL or OH) - the soil contains enough organic particles to influence the soil properties. Organic soils usually have a dark brown to black color and may have an organic odor. Often, organic soils will change color, for example, from black to brown, when exposed to the air. Organic soils normally will not have a high toughness or plasticity.

Outer Barrel - The steel piping that serves to both cut downwards and to line the borehole walls to prevent hole collapse.

Overshot Tool - The tool that attaches to the inner barrel so that the barrel may be lowered through the outer barrel to depth on the wireline. The overshot tool is designed to attach to, or release from, the inner tube at depth.

Parameters - Groundwater variables, pH, specific conductivity, temperature, turbidity.

Plasticity - The extent to which a soil may be rolled into a 1/8-inch thread and re-rolled when drier than the plastic limit.

Pitch - The distance along the axis of an auger flight that it takes for the helix to make one complete 360 degree turn.

Potentiometric Surface: An imaginary surface connecting points to which water would rise in cased wells from a given point in an aquifer (Lohman, 1979). It may be above or below the ground surface. The water table is a particular potentiometric surface for unconfined aquifers. "Potentiometric" is preferable to the term "piezometric" used by many in the past.

Pressure Transducer: A device installed in the well below the water surface that is capable of continuously providing very accurate water level measurements. The transducer is connected to a continuous data logger. Transducers are available in different pressure (and accuracy) ranges. The transducers should never be lowered into a water column below the operating pressure range of the transducer. Higher pressure range transducers are less accurate than lower pressure range transducers. As a rule, a multiplier of 2.3 can be used to estimate the maximum total amount of water above a transducer.

Purge water - Any water removed from the well via bailing, pumping, or air lift.

Residual Drawdown: Once a pump is shut off during a pumping test, water levels in pumping wells, observation wells, or piezometers will rise. This rise in total head results from the principle of superposition, and is commonly known as residual drawdown (‘s’ by convention). It is expressed as the difference between the static water level and the water level at time t' after the cessation of pumping.

Rising Head Slug Tests: Rising head slug testing requires submerging the slug under water in a well, and allowing the water level to stabilize to static conditions. The slug is then rapidly withdrawn from the well. After the slug is withdrawn from the well, the instantaneous water level will be at a level that is lower than the static water level. The rate at which the water level recovers to static condition is a function of the aquifer properties and of the well itself.

Rounded - Particles have smoothly curved sides and no edges.

Rotary Table - A mechanical or hydraulic assembly that transmits rotational torque to the kelly, which is connected to the drill pipe and the bit. The rotary table has a hole in the center through which the kelly passes.

Sand - Particles of rock that will pass a No. 4 (0.19 in. or 4.75-mm) sieve and be retained on a No. 200 (0.003 in. or 75-µm) sieve.

Saturated annulus - The portion of the annulus that is below the aquifer.

Silt (ML)- Soil passing a No. 200 (0.003 in. or 75-µm) sieve that is nonplastic or very slightly plastic and that exhibits little or no strength when air-dried. Individual silt particles are not visible to the naked eye.

Sieve Analysis - Determination of the particle-size distribution of soil, sediment, or rock by measuring the percentage of the particles that will pass through standard sieves of various sizes.

Slug: A solid pipe used to displace water by insertion or withdrawal from a well. Bailers may also be used for slug withdrawal only. The slug volume should be maximized based on field conditions. Different length slugs, capable of threading together, should be brought to the field to provide flexibility to the program. A typical slug used for a 2-inch-diameter monitoring well may be 1.5 inches in diameter and 6 to 10 feet in length.

Specific Capacity: The specific capacity is defined as the discharge rate per unit length of drawdown for a pumping well. Typically expressed in gallons per minute per foot of drawdown (gpm/ft).

Specific Yield: The specific yield is the volume of water released by gravity drainage from an unconfined aquifer from storage per unit surface area of the aquifer per unit decline in the watertable. Specific yield is also known as unconfined storativity, effective porosity, or drainable pore space. Specific yield is unitless and typically ranges from 0.01 to 0.3 (Kruseman and de Ridder, 1991).

Static Water Level: The non-pumping, stabilized water level in a cased well or piezometer. Usually recorded in the field as depth to water below a datum such as the top of casing. This term is usually reported in feet above mean sea level

Storativity: The storativity of a confined aquifer is the volume of water released from storage per unit surface area per unit change in head. For confined aquifers, stored water is released via aquifer compression and expansion of water. In an unconfined (watertable) aquifer, the storativity is equivalent to the specific yield and is also known as the storage coefficient.

Subangular - Particles are similar to angular description but have rounded edges.

Subrounded - Particles have nearly plane sides but have well-rounded corners and edges.

Transmissivity: The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. This term ("T" by convention) is simply the product of the hydraulic conductivity (K) and the aquifer thickness ("b" by convention).

$$T = Kb$$

Transmissivity may vary significantly due to spatial variations in both the thickness and conductivity of the aquifer. Transmissivity carries the units $\text{length}^2/\text{time}$. For aquifers, b is the thickness of the confined aquifer. For unconfined aquifers, b is the thickness of the saturated portion of the aquifer.

Thin-Walled Sampler - A sampling devise used to obtain undisturbed soil samples made from thin-wall tubing. The sampler is also known as a Shelby tube. The thin-wall sampler minimizes the most serious sources of disturbance: displacement and friction.

Total Head: The sum of the elevation head, the pressure head, and the velocity head at any given point in an aquifer.

Toughness - The strength of a soil, moistened near its plastic limit, when rolled into a 1/8-inch diameter thread.

Tremie Pipe - A device, usually a small-diameter pipe, that carries grouting materials to the bottom of the borehole and that allows pressure grouting from the bottom up without introduction of appreciable air pockets.

VOCs - Volatile organic compounds.

Water Level Indicator: A device used to measure static water levels. An electrical conductivity-based water level indicator capable of measuring to 0.01 foot accuracy is required for all measurements.

Wireline - The steel cable used to lower and retrieve cutting, coring and sampling equipment down the borehole.

Yield - The rate at which a well will produce water.

ATTACHMENT B

LITHOLOGIC LOGGING FORM

LOG OF BORING BY CUTTINGS

BORING NO: | PAGE OF

GEOLOGIST NAME:	PROJECT NO:	SITE NAME:	BORING LOCATION:

DRILLING TIME RECORD					DEPTH		HYDRAULIC PRESSURE	DRILLING ACTION	CALC. CONTENT	DESCRIPTION AND DRILLERS NOTES: (material, color, texture, hardness, and other notes)
DEPTH		TIME								
FROM	TO	FROM	TO	MIN.	FROM	TO				

ABBRVIATIONS:		CALC. CONTENT	HYD. PRESS
DRILLING ACTION		N: Non-calc.	N: None
E: Even smooth	SR: Slightly rough	S: Slightly	L: Low
C: Crunchy	MR: Moderatel rough	M: Moderately	M: Medium
I: Intermittently Rough	VR: Very rough	V: Very	F: Full

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BUILDING A BETTER WORLD

ATTACHMENT C

UNIFIED SOIL CLASSIFICATION SYSTEM

TABLE - A

Unified Soil Classification System

CRITERIA FOR ASSIGNING GROUP SYMBOLS AND NAMES			SOIL CLASSIFICATION	
			GROUP SYMBOL	GERERALIZED GROUP DESCRIPTIONS
Coarse-Grained Soils More Than 50% Retained On No. 200 Sieve	Gravels More Than 50% Of Coarse Fraction Retained On No. 4 Sieve	Clean Gravels Less Than 5% Fines	GW	WELL-GRADED GRAVELS
			GP	POORLY-GRADED GRAVELS
		Gravels With Fines More Than 12% Fines	GM	GRAVEL AND SILT MIXTURES
			GC	GRAVEL AND CLAY MIXTURES
	Sands 50% Or More Of Coarse Fraction	Clean Sands Less Than 5% Fines	SW	WELL-GRADED SANDS
			SP	POORLY-GRADED SANDS
		Sands With Fines More Than 12% Fines	SM	SAND AND SILT MIXTURES
			SC	SAND AND CLAY MIXTURES
Fine-Grained Soils 50% Or More Passes The No. 200 Sieve	Silts And Clays Liquid Limit Less Than 50	Inorganic	CL	NON-PLASTIC AND LOW PLASTICITY CLAYS
			ML	NON-PLASTIC AND LOW PLASTICITY SILTS
		Organic	OL	NON-PLASTIC AND LOW PLASTICITY ORGANIC CLAYS
				NON-PLASTIC AND LOW PLASTICITY ORGANIC SILTS
	Silts And Clays Liquid Limit 50 Or More	Inorganic	CH	HIGH PLASTICITY CLAYS
			MH	HIGH PLASTICITY SILTS
		Organic	OH	HIGH PLASTICITY ORGANIC CLAYS
				HIGH PLASTICITY ORGANIC SILTS
Highly Organic Soils	Primarily Organic Matter, Dark In Color, And Organic Odor		PT	PEAT

TABLE - B

Relative Density Or Consistency
Utilizing Standard Penetration Test Values

NONCOHESIVE SAMPLES (a)		COHESIVE SAMPLES (b)	
Relative Density	No. Blows/PerFt. (c)	Consistency	No. Blows/PerFt.
Very Loose	0 To 4	Very Soft	0 To 2
Loose	4 To 10	Soft	2 To 4
Compact	10 To 30	Firm	4 To 8
Dense	30 To 50	Stiff	8 To 15
Very Dense	Over 50	Very Stiff	15 To 30
		Hard	Over 30

(a) Soils consisting of gravel, sand, and silt, either separately or an combination, processing no characteristics of plasticity, with average particle diameter greater than 0.002 millimeters.

(b) Soils consisting generally of the Clay fraction, possessing the characteristics of plasticity with an average particle diameter of less than 0.002 millimeters.

(c) Refer to text or ASTM 0 1586-84 for a definition of N.

TABLE - C

Component Definitions By Gradation

COMPONENT	SIZE RANGE
Boulders	Greater than 12in. (300mm)
Cobbles	12in. to 3in. (300mm to 75mm)
Gravels	3 in. To No.4(4.76mm)
Coarse Gravel	3 in. To 3/4 in. (75mm to 19mm)
Fine Gravel	3/4 in. (19mm) To No.4 sieve (4.76mm)
Sand	No.4(4.76mm) To No.200(0.074mm)
Coarse Sand	No.4(4.76mm) To No.10(2.0mm)
Medium Sand	No.10(2.0mm) To No.40(0.42mm)
Fine Sand	No.40(0.42mm) To No.200(0.074mm)
Silt & Clay	Smaller Than No.200(0.074mm)

TABLE - D

Descriptive Terminology Denoting Component Proportions

DESCRIPTIVE TERMS	RANGE OF PROPORTION
Trace	0-5%
Little	5-12%
Some	12-30%
And	30-50%

TABLE - E

Descriptive Terms Denoting Gradation Of Granular Components

GRADATION DESIGNATION	ABBREVIATION SYMBOLS	DEFINING PROPORTIONS
Coarse To Fine Or Coarse Medium To Fine	C-F C-M-F	(All fractions greater than 10% of the component, but the medium component dominates)
Coarse To Medium	C-M	Less Than 10% Fine
Medium To Fine	M-F	Less Than 10% Coarse
Medium	M	Less Than 10% Coarse & Fine
Fine	F	Less Than 10% Coarse & Medium

TABLE - F

Sample Test Taken

- STANDARD PENETRATION TEST
- SHELBY TUBE
- GRAB SAMPLE
- CUTTINGS
- PENETRATION SAMPLER (3" O.D.)
- SPLIT SPOON SAMPLER (2.5" O.D.)
- WATER LEVEL DURING DRILLING
- MEASURED WATER LEVELS

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AUTOCAD FILE: SOILNDX.DWG

ATTACHMENT D

SOIL BORING LOG FORM

BORING LOG NUMBER:

LOCATION SKETCH

LOC. ID: SHEET ___ OF ___
PROJECT NAME: ELEVATION: DATUM:
INCLINATION: AZIMUTH: HAMMER WEIGHT: DRILL DATE:
DATE FINISHED:

DEPTH (UNITS)	BORING METHOD	SOIL PROFILE		SAMPLES					ADDITIONAL COMMENTS
		SOIL DESCRIPTION	GRAPHIC LOG	USCS	NUMBER	TYPE	BLOW COUNT/6"	RECOVERY	
0									
5									
10									
15									
20									
25									
30									
35									
40									
45									

DEPTH UNITS: ____________
DRILLING CONTRACTOR: ____________
DRILLER: ____________

LOGGED BY: ____________
CHECKED BY: ____________

REV. No.	REVISIONS	REV. DATE	DESIGN BY	DRAWN BY	REVIEWED AND SIGNED BY

SOIL BORING LOG FORM

MWH

PROJECT No.:
AutoCAD FILE:
SCALE: FIGURE No.:

ATTACHMENT E

CRITERIA FOR DESCRIBING PLASTICITY

CRITERIA FOR DESCRIBING PLASTICITY	
Description	**Criteria**
Nonplastic	A 1/8-in. (3-mm) thread cannot be rolled at any water content
Low	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit
Medium	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit.
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit.

ATTACHMENT F

CRITIERIA FOR DESCRIBING DENSITY AND CONSISTENCY

DENSITY/CONSISTENCY BASED UPON BLOW COUNTS							
Density (Sand and Gravel) Blows/ft*				**Consistency (Silt and Clay) Blows/ft***			
Term	**1.4" ID**	**2.0" ID**	**2.5" ID**	**Term**	**1.4" ID**	**2.0" ID**	**2.5" ID**
very loose	0-4	0-5	0-7	very soft	0-2	0-2	0-2
loose	4-10	5-12	7-18	soft	2-4	2-4	2-4
medium dense	10-29	12-37	18-51	medium stiff	4-8	4-9	4-9
dense	29-47	37-60	51-86	stiff	8-15	9-17	9-18
very dense	>47	>60	>86	very stiff	15-30	17-39	18-42
				hard	30-60	39-78	42-85
				very hard	>60	>78	>85
* 140 lb. hammer dropped 30 inches							

CRITERIA FOR DESCRIBING CONSISTENCY BASED UPON THUMB TEST	
Description	**Criteria**
Very soft	Thumb will penetrate soil more than 1 in. (25 mm)
Soft	Thumb will penetrate soil about 1 in. (25 mm)
Firm	Thumb will indent soil about 1/4 in. (6 mm)
Hard	Thumb will not indent soil but readily indented with thumbnail
Very Hard	Thumbnail will not indent soil

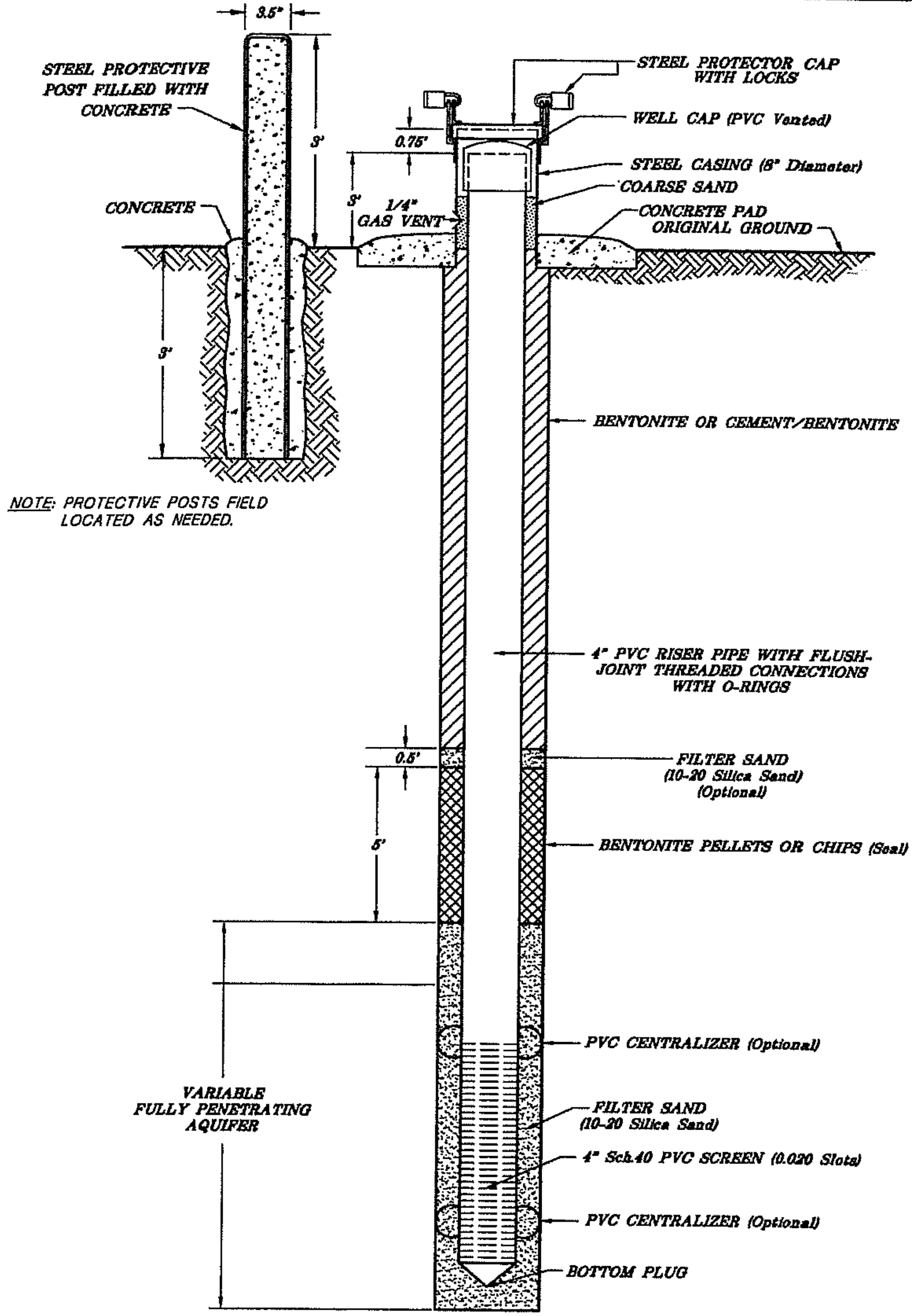
ATTACHMENT G

CRITIERIA FOR DESCRIBING STRUCTURE

CRITERIA FOR DESCRIBING STRUCTURE	
Description	**Criteria**
Stratified	Alternating layers of varying material or color with layers at least 6 mm thick; note thickness
Laminated	Alternating layers of varying material or color with the layers less than 6 mm thick; note thickness
Fissured	Breaks along definite planes of fracture with little resistance to fracturing
Slickensided	Fracture planes appear polished or glossy, sometimes striated
Blocky	Cohesive soil that can be broken down into small angular lumps which resist further breakdown
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay; note thickness
Homogeneous	Same color and appearance throughout

ATTACHMENT H

TYPICAL MONITOR WELL INSTALLATION FORM



Project No.:	Design By:	Scale: N.T.S.
File: TYP-WELL.DWG	Drawn By:	Date:

MWH

TYPICAL MONITORING WELL INSTALLATION

ATTACHMENT I

MONITORING WELL CONSTRUCTION FORM

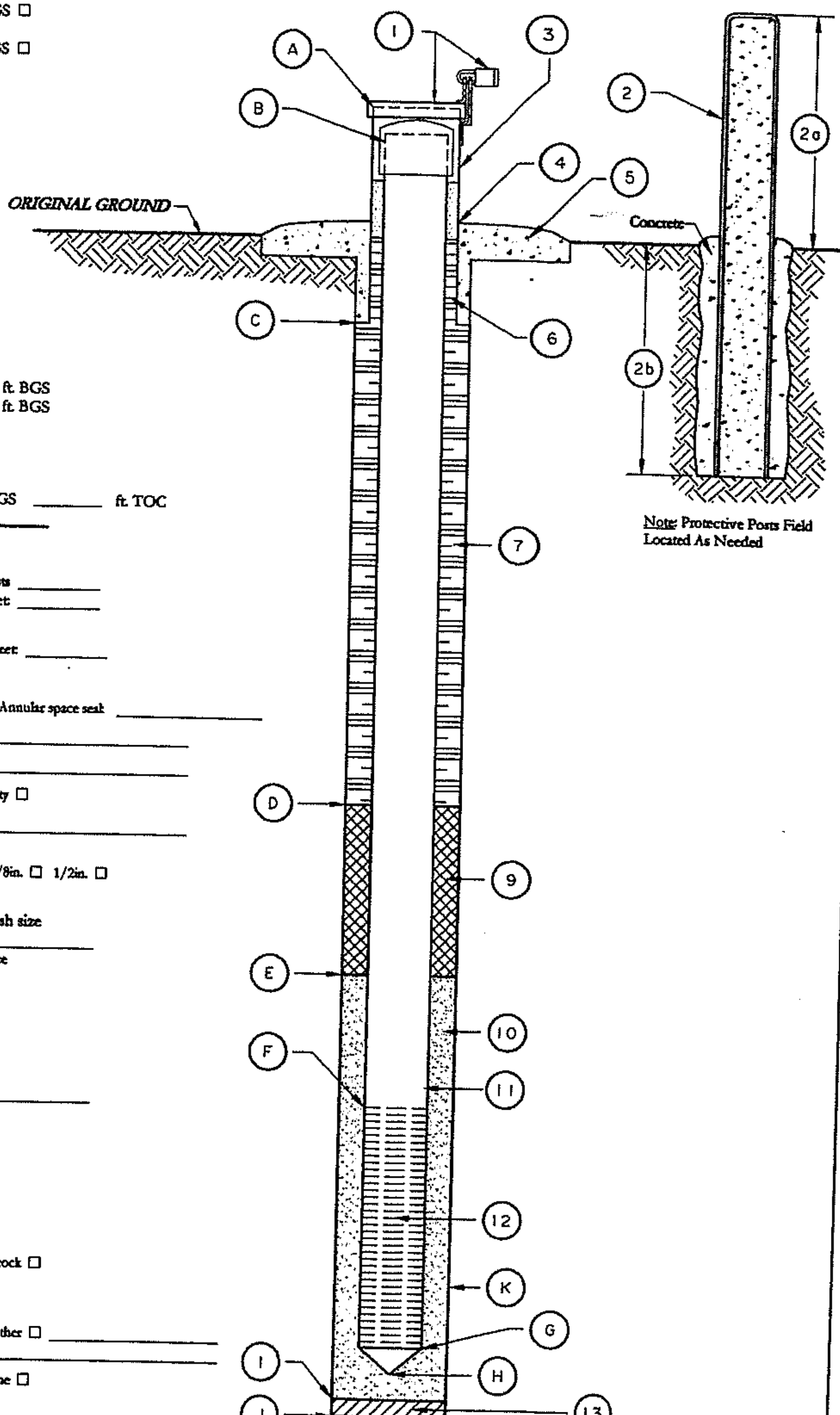
Facility/Project Name: ______________________ **Date Well Installed:** From ________ To ________

Well Number: ______________ Well Installed By (Person's Name & Firm) ______________________

Type of Protective Cover:
Above-Gound ☐
Flush-To-Ground ☐

NOTE: Use Ground Surface (BGS or AGS) for all depth measurements

- (A) - Protective casing ________ ft. BGS ☐ or AGS ☐
- (B) - Well casing, top ________ ft. BGS ☐ or AGS ☐
- (C) - Surface seal, bottom ________ ft. BGS
- (D) - Bentonite seal, top ________ ft. BGS
- (E) - Primary filter, top ________ ft. BGS
- (F) - Screen joint, top ________ ft. BGS
- (G) - Screen joint, bottom ________ ft. BGS
- (H) - End cap bottom ________ ft. BGS
- (I) - Filter pack, bottom ________ ft. BGS
- (J) - Borehole, bottom ________ ft. BGS
- (K) - Borehole, diameter ________ in. to ________ ft. BGS; ________ in. to ________ ft. BGS
- (L) - O.D. well casing ________ in.
- (M) - I.D. well casing ________ in.
- (N) - 24 hr. water level after completion ________ ft. BGS ________ ft. TOC



Note: Protective Posts Field Located As Needed

1. - Cap and Lock? Yes ☐ No ☐
2. - Protective posts? Yes ☐ No ☐ No. of Posts ________
   a. Height AGS: Feet ________ b. Depth BGS: Feet ________
3. - Protective casing:
   a. Inside diameter: Inches ________ b. Depth: Feet ________
4. - Drainage port (s)? Yes ☐ No ☐
5. - Surface seal material a. Cap: ____________ b. Annular space seal ____________
6. - Material between well casing and protective casing: ____________
7. - Annular space seal: Mix: ____________
   - How installed: Tremie ☐ Tremie pumped ☐ Gravity ☐
8. - Centralizers: No ☐ Yes ☐ Depths (BGS) ____________
9. - Bentonite seal:
   a. Bentonite granules ☐ or b. Bentonite pellets 1/4in. ☐ 3/8in. ☐ 1/2in. ☐
   c. ____________ ☐ other
10. - Filter pack material: Manufacturer, product name, & mesh size
    a. ____________
    b. Volume added ________ ft./3 ________ Bags/Size
11. - Well casing: Flush threaded PVC schedule 40 ☐
    Flush threaded PVC schedule 80 ☐
    ____________ Other ☐
12. - Screen material: ____________
    a. Screen type: ____________
    Factory cut ☐ Continuous slot ☐ Other ☐ ____________
    b: Manufacturer ____________
    c: Slot size: ____________
    d: Slotted length: ____________
13. - Backfill material (below filter pack): None ☐
    ____________ Other ☐
14. - USCS classification of soil near screen None ☐
    GP ☐ GM ☐ GC ☐ GW ☐ SW ☐ SP ☐
    SM ☐ SC ☐ ML ☐ MH ☐ CL ☐ CH ☐ Bedrock ☐
15. - Sieve analysis attached? Yes ☐ No ☐
16. - Drilling method used: Rotary ☐ Hollow Stem Auger ☐ Other ☐ ____________
17. - Drilling fluid used: Water ☐ Air ☐ Drilling Mud ☐ None ☐
18. - Drilling additives used? Yes ☐ No ☐
    Describe: ____________

REV. No.	REVISIONS	REV. DATE	DESIGN BY	DRAWN BY	REVIEWED AND SIGNED BY

MWH

PROJECT No.: 1004001011803	
AutoCAD FILE: Well Construction Form	
SCALE: Not To Scale	FIGURE No:

WELL CONSTRUCTION FORM

ATTACHMENT J

WELL DEVELOPMENT RECORD AND WELL VOLUME CHART

WELL DEVELOPMENT RECORD

Well Number:

Job No. ____________ Project Name: ____________ Page: ___ of ___

Date(s): ____________

Developed by: ____________

Measuring Point (MP) of Well: ____________

Screened Interval (ft bgs): ____________

Filter Pack Interval (ft bgs): ____________

Development Method: ____________

Comments: ____________

Starting H_2O Level (BMP): ____________

Casing Stickup TOC (ft): ____________

Casing Diameter (in ID): ____________

Casing Volume (gal): ____________

QUALITY ASSURANCE

Methods (describe)

Cleaning Equipment:

Development:

Disposal of Purge Water:

Instruments (indicate make, model, id.)

Water Level: Thermometer:

pH Meter: Field Calibration:

Conductivity Meter: Field Calibration:

Turbidity Meter: Field Calibration:

Other: Field Calibration:

DEVELOPMENT MEASUREMENTS

Date/Time	Cumul. Vol. (gal)	Temp. (C)	Field EC (____)	Color	Turbidity	Other ____	Remarks

Total Discharge (gal): ____________ Casing Volumes Purged: ____________

Observations/Comments: ____________

Abbreviations:

BMP = below measuring point

BGS = below ground surface

Cumul. Vol. = cumulative volume removed

ID = inside diameter

C = Celsius

gal = gallons

ft = feet

in = inches

MWH

Filename: Well-devel.dwg

ATTACHMENT K

WATER LEVEL READING FORM

Record of Water Level Readings

Job Number: Project Name: Location:

Loc. ID	Date	Time	Measuring Device / Unit Number	Refrence Point	Depth to Water	Recorded By	Comments

Record of Water Level Readings, Rev: 4/10/2008

MWH

BUILDING A BETTER WORLD

ATTACHMENT L

TIME INTERVALS FOR MANUAL AND ELECTRONIC MEASUREMENTS OF DRAWDOWN

SUGGESTED MANUAL MEASUREMENT FREQUENCY USING CALIBRATED ELECTRONIC WATER-LEVEL INDICATORS

ELAPSED TIME	MEASUREMENT FREQUENCY
0-20 minutes	30 seconds
20-40minutes	2 minute
40-60 minutes	5 minutes
60-120 minutes	10 minutes
2-12 hours	1 hour
12 hours to 3 days	2 hours

LOGARITHMIC TIME INTERVAL SCHEDULE FOR PRESSURE TRANSDUCERS AND DATA LOGGERS

LOG CYCLE	MEASUREMENT INTERVAL	TOTAL DATA POINTS PER CYCLE
0-20 seconds	0.2 second	101
20 -60 seconds	1 second	40
1-10 minutes	12 seconds	45
10-100 minutes	2 minutes	45
100-1,000 minutes	20 minutes	45
1,000-10,000 minutes	200 minutes	45

APPENDIX B
UPDATED WORK BREAKDOWN STURCTURE
and SUMMARY of 2008 ACTIVITIES

UPDATED PROGRAM WORK BREAKDOWN STRUCTURE

Appendix B presents the program work breakdown structure for the eleven activities to be completed in 2008 in support of SI Task 3—Geology and Groundwater Investigation, Subtask 3c—Phase IIb Investigation. Table B-1 shows the updated Program Work Breakdown Structure, Tasks, Subtasks, and Activities. Summaries of each 2008 activity are provided below.

TABLE B-1
PROGRAM WORK BREAKDOWN STRUCTURE
TASKS, SUBTASKS, AND ACTIVITIES

TASK	SUBTASK	ACTIVITY
Task 1—Surface Water and Sediment Investigation	Subtask 1a—Investigation of historical irrigation practices	
	Subtask 1b—Surface water and sediment sampling	Activity 1b-1—impacted riparian zones
		Activity 1b-2—fish tissue quality investigation
	Subtask 1c—2006 Surface Water Sampling	
	Subtask 1d—2007&2008 Surface Water Sampling	
Task 2—Air Investigation	Subtask 2a—Data compilation	
Task 3—Geology and Groundwater Investigation	Subtask 3a—Phase I Investigation	Activity 3a-1—review available hydrogeologic information
		Activity 3a-2—well inventory
		Activity 3a-3—spring and seep survey
		Activity 3a-4—spring and dump seep flow characterization
		Activity 3a-5—sampling existing mine and domestic wells, springs and seeps
		Activity 3a-6—revise conceptual hydrogeologic site model
	Subtask 3b—Phase II Investigation	Activity 3b-1—aerial mapping of Ballard Mine
		Activity 3b-2—focused investigation of existing wells
		Activity 3b-3—existing well sampling and groundwater level monitoring
		Activity 3b-4—revise conceptual hydrogeologic site model
		Activity 3b-5—preparation of a technical memorandum for monitoring well installations
		Activity 3b-6—develop selenium attenuation conceptual model
		Activity 3b-7—2006 groundwater sampling
	Subtask 3c—Phase IIb Investigation	Activity 3c-1—complete direct-push groundwater sampling program
		Activity 3c-2—prepare technical memorandum for monitoring well installations and install eight monitoring wells
		Activity 3c-3—evaluate alluvial/colluvial material and bedrock hydraulic conductivities
		Activity 3c-4—sample existing groundwater monitoring wells and groundwater level monitoring
		Activity 3c-5—perform detailed spring/seep survey northeast of MMW022
		Activity 3c-6—confirm Wells Formation flow direction – Henry Mine
		Activity 3c-7—evaluate geologic structure (flexure) north of Enoch Valley Mine
		Activity 3c-8—perform geochemical typing of wells, seeps, and springs

TABLE B-1 PROGRAM WORK BREAKDOWN STRUCTURE TASKS, SUBTASKS, AND ACTIVITIES		
TASK	**SUBTASK**	**ACTIVITY**
		Activity 3c-9—evaluate potential mass movement at waste dump sites.
		Activity 3c-10—water balance modeling at waste dumps and Wells Formation at Henry Mine
		Activity 3c-11—revise conceptual hydrogeologic site model
Task 4—Soil Investigation	Subtask 4a—Water balance investigation	
	Subtask 4b—Characterization of extent of riparian zone soil contamination at streams, ponds, seeps, springs, and wetlands	
	Subtask 4c—Characterization of waste rock dump extent of soil contamination	
	Subtask 4d—Agronomic testing of unreclaimed, poorly reclaimed, and well reclaimed land	
Task 5—Aquatic Ecological Investigation	Subtask 5a—Stream habitat assessment	
	Subtask 5b—Fish tissue quality investigation	
Task 6—Terrestrial Ecological Investigation	Subtask 6a—Habitat assessment of ponds, wetlands, and non-fish-bearing streams	
	Subtask 6b—Characterization of extent of riparian zone vegetation contamination at streams, ponds, seeps, springs, and wetlands	
	Subtask 6c—Evaluate potential replacements for alfalfa in reclamation seed mix	
	Subtask 6d—Identification and location of known selenium absorber species	
	Subtask 6e—Veterinary toxicology panel on livestock utilization of reclaimed land	
	Subtask 6f—Characterization of waste rock dump extent of vegetation contamination	
	Subtask 6g—Performance monitoring of non-seleniferous cap	
Task 7—Facilities Investigation		
Task 8—Data Validation	Subtask 8a—Surface water	
	Subtask 8b—Sediment	
	Subtask 8c—Groundwater	
	Subtask 8d—Soil	
	Subtask 8e—Fish	
	Subtask 8f—Vegetation	
Task 9—Data Evaluation	Subtask 9a—Surface water	
	Subtask 9b—Sediment	
	Subtask 9c—Groundwater	
	Subtask 9d—Soil	
	Subtask 9e—Fish	
	Subtask 9f—Vegetation	
Task 16*—Reporting		
Task 17—Project and Program Management		
Task 18—Meetings		

*Tasks 10–15 are reserved for the EE/CAs.

Activity 3c-1 — Complete Direct-Push Groundwater Sampling Program

Details regarding the direct-push groundwater sampling program are summarized in MWH, 2008a. The direct-push groundwater sampling investigation is scheduled to commence on May 5, 2008. During the direct-push sampling program, a reconnaissance of the Little Blackfoot River, north of MMP043, will be conducted to learn if there is a shallow alluvial groundwater system overlying the Quaternary Basalt. If a shallow alluvial groundwater system is observed, additional direct-push locations will be advanced to characterize potential selenium contamination within the shallow alluvial groundwater system.

Activity 3c-2 — Prepare a Technical Memorandum for Monitoring Well Installations and Install Eight Monitoring Wells

Eight new monitoring wells will be installed at the mine sites to address data gaps related to identified flow paths associated with potential contaminant sources. Details regarding the installation of the monitoring wells are described in main body of this report. The monitoring well installation is scheduled to commence in June of 2008.

Activity 3c-3 — Evaluate Alluvial/Colluvial Material and Bedrock Hydraulic Conductivities

An evaluation will be completed to assess the hydraulic conductivities of the alluvial/colluvial material and bedrock at the three mine sites. For the alluvial/colluvial material, the majority of the evaluation will be completed during the direct-push groundwater sampling program. Hydraulic conductivities will be assessed by performing grain size analysis on soil samples collected from the direct push bore holes or by in-situ slug testing. Slug testing will also be completed at existing groundwater monitoring wells installed in the alluvial/colluvial material. Possible existing alluvial/colluvial) monitoring well locations to be evaluated include; MMW012 and MMW017 (if groundwater is present), MMW010, and MMW014. For evaluating the hydraulic conductivities in existing monitoring wells installed in bedrock, the following monitoring wells will be tested: MMW007, MMW018 (alluvial/Dinwoody Formation) MMW009, MMW021 (Wells Formation), MMW022 (Dinwoody Formation). SOPs for slug testing can be found in the Appendix A of this report.

Activity 3c-4 — Sample Existing Groundwater Monitoring Wells and Groundwater Level Monitoring

Existing agricultural, domestic, monitoring, and production wells will be sampled in spring and fall of 2008. Table B.2 lists the existing wells that will be sampled.

Table B-2 2008 Program Sampling Locations					
Feature		Name	ID	Latitude	Longitude
Agricultural Wells		School Bus Well	MAW001	42 53 15.00	111 26 40.00
		Sharp Field Well	MAW002	42 53 51.00	111 26 42.00
		Peterson Field Well	MAW003	42 53 24.00	111 27 21.60
		Dredge Field Well	MAW004	42 51 57.01	111 29 22.21
		Vasser Windmill Field Well	MAW005	42 51 44.32	111 23 08.80
		Godfrey Field Well West	MAW006	42 51 59.54	111 30 49.85
		Godfrey Field Well North	MAW007	42 52 30.00	111 29 49.20
		Torgeson Well	MAW008		
Domestic Wells		Peterson House Well	MDW001	42 53 24.00	111 27 26.00
		Thompson House Well	MDW002	42 54 18.00	111 26 49.20
		Taylor House Well	MDW003	42 52 30.00	111 26 46.00
		Godfrey House Well	MDW004	42 49 26.40	111 33 14.40
		Cedar Bay RV Park Well	MDW005	42 54 32.40	111 31 51.60
		Ellis House Well	MDW006	42 54 43.20	111 28 48.00
Mine	**Feature**	**Name**	**ID**	**Latitude**	**Longitude**
Enoch Valley Mine	Monitoring Wells	South of EVM South Dump; near edge of dump footprint	MMW007	42 51 48.50	111 23 34.40
		South of EVM South Dump; south and downgradient of MMW007	MMW008	41 51 48.60	111 23 29.80
		Central North Dump (MWD091)	MMW009	42 53 34.60	111 25 33.80
		Northwest of EVM North Dump in Lone Pine Creek alluvial flow field	MMW012	42 53 27.10	111 26 08.90
		SW of EVM in Rasmussen Creek alluvial flow field	MMW013	42 52 05.70	111 24 12.0
	Production Wells	EVM Shop Well	MPW019	42 52 37.40	111 25 16.53
Henry Mine	Monitoring Wells	Henry North Pit Well N	MMW004	42 54 07.70	111 29 46.50
		Southeast of Center Henry Pit; near MPW023	MMW010	42 52 22.30	111 27 51.30
		Northwest of Center Henry Pit; south of Little Blackfoot River	MMW011	42 53 48.30	111 29 30.00
		Southeast of Henry Mine center pit in Lone Pine creek alluvial flow field	MMW014	42 51 59.30	111 27 05.20
		North of Henry Mine center pit	MMW019	42 53 50.20	111 29.25.40
		Northeast lobe of Henry Mine waste rock dump MWD086	MMW022	42 53 09.20	111 28 18.30
		Henry Mine North Pit	MMW023	42 54 20.50	111 30 27.50
	Production Wells	Henry South Pit Well	MPW022	42 52 03.50	111 27 28.40
		Henry Center Pit Well	MPW023	42 52 17.70	111 27 47.20
Ballard Mine	Monitoring Wells	Ballard Pit East Well	MMW001	42 49 36.39	111 29 03.32
		South of West Ballard Pit; south of waste rock dumps	MMW006	42 49 20.0	111 29 03.00
		Northwest of Ballard Mine into Long Valley Creek alluvial flow field	MMW017	42 49 59.60	111 29 47.40
		East of Ballard Mine in Wooley Valley Creek alluvial flow field	MMW018	42 49 39.40	111 28 04.50
		East side of West Ballard Pit (MMP035); replacement of MMW001	MMW020	42 49 36.40	111 29 03.30
		West side of West Ballard Pit (MMP035); replacement MMW002	MMW021	42 49 35.6	111 29 23.90

Groundwater Sample Collection

Prior to groundwater sampling, measurement of the static water level will be performed using either a steel tape or electric probe. The same measuring point on the casing will be used to ensure the measurements are consistent. For MWH field studies, the wellhead reference point will be at the top of casing, north side.

Wells will be purged and sampled either through the traditional 3-casing volume, parameter-stabilization purging method or through the use of low flow sampling techniques. All groundwater wells will be sampled as described in the PgmQAP and according to SOP-NW-5.3, Collection of Groundwater Quality Samples, which is located in Appendix B of the PgmQAP (MWH, 2004).

Groundwater Analyses

All the wells listed in Table B-2 will be analyzed based on the parameters listed in Table B–3, *2008 Groundwater Analytes for Existing Wells*. All analyses will be on a total basis, in addition, the COPC metals identified in the AOC will be analyzed for dissolved concentrations.

Table B-3 2008 Groundwater Analytes for Existing Wells				
Parameter	**Method**	**EDL**	**Reporting Units**	**Holding Time (days)**
alkalinity, total	SM2320B	2	mg/L	14
aluminum	M200.7 ICP	0.03	mg/L	180
antimony*	M200.8 ICP/MS	0.0004	mg/L	180
Arsenic*	M200.8 ICP/MS	0.0001	mg/L	180
Barium*	M200.7 ICP	0.0001	mg/L	180
beryllium*	M200.7 ICP	0.0001	mg/L	180
cadmium	M200.8 ICP/MS	0.0001	mg/L	180
calcium	M200.7 ICP	0.2	mg/L	180
chloride	M300.0	0.5	mg/L	28
chromium*	M200.8 ICP/MS	0.0001	mg/L	180
cobalt*	M200.7 ICP	0.01	mg/L	180
copper*	M200.7 ICP	0.01	mg/L	180
gross alpha	M900.0	2	pCi/L	180
gross beta	M900.0	4	pCi/L	180
hardness	Calculation	1.5	mg/L	-
iron	M200.7 ICP	0.01	mg/L	180
ferrous iron, dissolved (Field)	HACH	0.01	mg/L	-
ferric iron, dissolved	Calculation	0.01	mg/L	-
lead*	M200.8 ICP/MS	0.0001	mg/L	180
manganese	M200.8 ICP/MS	0.0005	mg/L	180
magnesium	M200.7 ICP	0.2	mg/L	180
mercury*	M245.1	0.0002	mg/L	28
molybdenum*	M200.7 ICP	0.01	mg/L	180
nickel	M200.8 ICP/MS	0.0006	mg/L	180
Nitrogen (total nitrate-nitrite)	M 353.2	0.02	mg/L	28
orthophosphate	M 365.1	0.005	mg/L	28
pH	M150.1	0.1	pH	-
potassium	M200.7 ICP	0.3	mg/L	180
selenium	SM3114 B, AA-Hydride	0.001	mg/L	180
silver*	M200.7 ICP	0.01	mg/L	180
sodium	M200.7 ICP	0.3	mg/L	180
sulfate	M300.0	0.5	mg/L	28
thallium*	M200.8 ICP/MS	0.0001	mg/L	180
total dissolved solids+	M160.1	10	mg/L	7
total suspended solids+	M160.1	10	mg/L	7
uranium*	M200.8 ICP/MS	0.0001	mg/L	180
vanadium	M200.8 ICP/MS	0.0002	mg/L	180
zinc	M200.8 ICP/MS	0.002	mg/L	180

* -- Analytes to be analyzed only in groundwater collected from monitoring wells MMW007, MMW009, MMW010, MMW012, MMW014, MMW017, and MMW018, and surface water at sites not previously sampled for the expanded list of analytes.

+ -- Analyte to be analyzed only in groundwater collected from monitoring well MMW009 and 5% of these monitoring wells: MMW001, MMW004, MMW009, MMW011, MMW013, MMW014, MMW017, MMW019, MMW020, and MMW022.

bicarbonate and carbonate to be analyzed only in groundwater collected from monitoring wells used for geochemical typing.

Methods are for media (non-blank) samples.

Equipment and field blanks will be analyzed for unfiltered results. For regulatory compliance, all media samples will be analyzed for unfiltered metals.

EDL – Estimated Detection Limit; the laboratory analytical limit does not reflect possible sample-specific elevation of the reporting limit due to dilution, contamination or other issues identified during the data validation process.

Activity 3c-5 — Perform Detailed Spring/Seep Survey Northeast of MMW022

A spring/seep survey will be conducted to assess whether groundwater is discharging in the drainage northeast of monitoring well MMW022. Monitoring well MMW022 was completed in the Dinwoody Formation. A groundwater sample collected from monitoring well MMW022 had a selenium concentration of 0.016 mg/l, indicating some impacts to the Dinwoody Formation. If springs/seeps are found, a surface expressed groundwater sample will be collected and analyzed. Information from the survey will be used to further refine the groundwater data gaps in the intermediate Dinwoody Formation flow system.

Activity 3c-6 — Confirm Wells Formation Flow Direction - Henry Mine

Monitoring wells MMW011 and MMW023 were completed in the Wells Formation. The two monitoring wells were surveyed in mid-winter but there was a problem with the survey. Groundwater elevations in monitoring wells MMW-11 and MMW023, based on the survey, indicate a probable northwest trending groundwater flow direction which supports the conceptual model for the regional Wells Formation flow path. To validate the conceptual model, monitoring wells MMW011 and MMW023 will be resurveyed and groundwater elevations corrected based on the new survey. To confirm the northwest trending flow direction, the corrected groundwater elevations will be coupled with groundwater elevations from a surfaced expressed groundwater spring emanating from a Wells Formation outcrop.

Activity 3c-7 — Evaluate Geologic Structure (flexure) North Enoch Valley Mine

A geologic structure (flexure) is located in the northern portion of the Enoch Valley Mine. At this time, this geologic structure is not thought to be a significant hydrogeologic feature. However, the feature's character needs to be assessed. The assessment will include reviewing any geologic information specific to the area and completing a geologic reconnaissance of the area.

Activity 3c-8 — Perform Geochemical Typing of Wells, Seeps, and Springs

Major ion data were obtained from each well, spring and seep sampling station and has been used to evaluate the ion balances as a quality control check. The data include concentrations for the cations, calcium, magnesium, sodium and potassium, and the anions, sulfate, chloride, bicarbonate and carbonate. We will be performing the geochemical typing this year, using either piper plots, stiff plots, PCA plots, or some other classification plotting. The results of this analysis will be reported in the 2008 Hydrogeologic Report.

Activity 3c-9—Evaluate Potential Mass Movement at Waste Dumps

A visit will be made to each waste dump to observe potential mass movement. The visit will include a walk around the toe of each waste dump to assess whether the waste dump has moved relative to its original post construction position. The waste dump slopes will be walked to observe indications of slope movement such as break in slope angles, terraces, ground cracks, tilted trees, and eroded bare slopes. The results of the evaluation will be reported in a technical memorandum to be issued in November of 2008.

Activity 3c-10 – Water Balance Modeling at Waste Dumps and Wells Formation at Henry Mine

A water balance model for waste dumps will be created using GoldSim, a probabalist simulation model, and HELP 3.07, a quasi-two-dimensional, deterministic, water-routing model for evaluating water balances for landfills, cover systems, and other solid waste containment facilities (e.g., waste rock facilities). This approach was selected due to the significant variability observed between and within waste rock facilities at the three mines being characterized. In general, using GoldSim, the fourteen input variables used in the HELP 3.07 model are treated stochastically. GoldSim runs these stochastic inputs through HELP 3.07 and annual results for runoff, infiltration, storage, etc. are returned back to the GoldSim model. These generic data are then used to develop inputs for individual waste dumps based on field data collected at individual waste dumps. Results of the water balance modeling will be presented in the 2008 Hydrogeologic Report.

Activity 3c-11 — Revise Conceptual Hydrogeologic Site Model

The conceptual hydrogeologic site model will be revised based on the information developed from completion of Phase IIb activities.

Schedule

A preliminary schedule for when the eleven activities will be completed is presented in Table B-4.

Table B-4
Preliminary Activity Schedule

	Month							
Activity	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
3c-1-complete direct-push groundwater sampling program								
3c-2- prepare technical memorandum for monitoring well installations and install eight monitoring wells								
3c-3-evaluate alluvial/colluvial material and bedrock hydraulic conductivities								
3c-4-sample existing groundwater monitoring wells and groundwater level monitoring								
3c-5-perform spring/seep survey northeast of MMW022								
3c-6-confirm Wells Formation flow direction – Henry Mine								
3c-7-evaluate geologic structure (flexure) north of Enoch Valley Mine								
3c-8-perform geochemical typing of wells, seeps, and springs								
3c-9-evaluate potential mass movement at waste dump sites								
3c-10 water balance modeling at waste dumps and Wells Formation at Henry Mine								
3c-11-revise conceptual hydrogeologic site model								

References

MWH, 2008. *Draft Direct-Push Groundwater Sampling Work Plan, Enoch Valley, Henry, and Ballard Mines.* Prepared by MWH for P4 Production, Southeast Idaho Mine-Specific Selenium Program, April 2008.